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Adjusting Quality Index Log Values to Represent Local and Regional Commercial Sawlog Product Values

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by

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INTRODUCTION

A SAWMILL operator should be able to accurately predict the expected product volume and value of a log prior to purchase and processing if he is to manage his enterprise efficiently. Considerable methodology and procedure have been developed to assist him in this prediction. Many systems of log grades for hardwood species have been established which segregate the logs into groups based on estimated yields and gross value.

The quality-index (Q.I.) concept (Herrick 1946)[1] provides a method for determining log product values. It is based on hardwood lumber-grade yields and prices, and makes the computation of log values relatively easy.

All of these aids use lumber-grade yields to predict log product values. In other words, the value of a hardwood log is computed on the assumption that the log is sawed into 4/4 lumber, in an adequate mill, by a sawyer skilled in cutting standard graded hardwood lumber.

A number of problems are immediately perceived by the sawmill operator who is a potential user of these aids.

He asks, "What is the relationship between my mill and this so-called adequate mill? How does the skill of my sawyer compare with the skill of this mythical sawyer? What is the relationship between the log-grade yield patterns used by these aids and those of my mill, especially when I may saw some timbers, ties and other products rather than all factory grade 4/4 lumber?"

These are relevant questions which signal the fact that it is necessary to bridge this credibility gap if more operators are to successfully employ some of the old aids as well as new developments which are forthcoming.

A series of research papers have been and are being prepared which use the Q.I. concept as a base for log and tree valuation.

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[1] Names and/or dates in parenthesis refer to Literature Cited, p. 15.

Therefore, the primary purpose of this paper is not only to report the results of a comparative analysis as to how well the Q.I. method predicts log product values when compared to commercial sawmill log output values, but also to develop a methodology which will facilitate the comparison and provide the adjustments needed by the sawmill operator.

The commercial sawlog values as derived in an independent study of seven sawmills in southeastern Ohio and eastern Kentucky were compared with Q.I. values developed for an analysis of log and tree valuation. (Whittaker and McCauley 1966). Six different species were compared: red oak, black oak, scarlet oak, white oak, chestnut oak, and yellow-poplar.

QUALITY INDEX - WHAT IT IS AND WHAT IT DOES

The quality-index (Q.I.) concept as developed by Herrick and refined by other researchers, was employed in this analysis to put log grades on a lumber value basis. Essentially, the Q.I. is a single number, a percentage that expresses the volume and value of a log in terms of different grades of 4/4 lumber. In formula form it appears as (Herrick 1946):

$$\begin{aligned} \text{Q.I.} = {} & (\%\ \text{FAS} \times PR_{FAS}) + (\%\ \text{SEL} \\ & \times PR_{SEL}) + (\%\ \text{No. 1 Common} \times \\ & PR_{No\ 1C}) + \ldots\ldots\ldots\ldots\ldots\ldots (\%\ \text{3A Common} \times \\ & PR_{No\ 3AC}) \end{aligned}$$

wherein

$\%$ FAS—means the percentage of the volume of the lumber sawed from a log in First and Seconds lumber grade.

PR_{FAS}—means the standard price relative for FAS lumber.

Two sets of data were used to develop a Q.I.: (1) lumber-grade yields by log grade, log diameter, and species and (2) lumber-price relatives, i.e., lumber-price ratios with 4/4 No. 1 Common as the base grade. Prices were derived from regional price reports and averaged for a period of five years.

In this analysis, U.S. Forest Service hardwood log grades for standard factory lumber, F_1, F_2, F_3 grades, and construction and local use classes were used (Ostrander et al. 1965).

Lumber-grade yield estimates were obtained from the Forest Products Laboratory publication *Hardwood log grades for standard lumber* (Vaughn, Walling, McDonald, and Bulgrin 1966). The erratic nature of the basic data, especially in the larger diameter classes, made it necessary to hand-curve the yield data to make it useful for developing the Q.I.'s.

Lumber price relatives used here were developed from the *Hardwood Market Report* (Lemsky 1962-1966) for the base period 1962-1966.

Prices were averaged over the five year period and the ratios, i.e., the average price of the various grades relative to the average price of No. 1 Common lumber, were determined. The price relatives (P.R.) for No. 1 Common are always 1.00, whereas the P.R.'s for hardwood lumber grades FAS and SEL are above 1.00 and the P.R.'s for No. 2 Common, No. 3A and 3B Common are below 1.00 (table 1).

Table 1.—*Lumber price relatives by grade and species*[1]

	Lumber grade							
Species	FAS	SEL	SAPS	No. 1C	No. 2C or 2AC	No. 2BC	No. 3AC	No. 3BC
Red oak	1.74	1.65	—	1.00	0.67	—	0.59	0.40
Black oak	1.74	1.65	—	1.00	0.67	—	0.59	0.40
Scarlet oak	1.74	1.65	—	1.00	0.67	—	0.59	0.40
White oak	1.90	1.81	—	1.00	0.68	—	0.59	0.40
Chestnut oak	1.90	1.81	—	1.00	0.68	—	0.59	0.40
Yellow-poplar	1.45	1.38	1.31	1.00	0.69	0.47	0.25	0.25

[1] Based on 1962-66 prices from the *Hardwood Market Report* for Appalachian hardwoods, f.o.b. mills, Johnson City, Tennessee area with 4/4 thickness, plain-sawed No. 1 Common grade as the reference grade.

Once the lumber-grade yields and the price relatives are obtained, it is possible to calculate the Q.I.'s. For example, given a 16-inch diameter chestnut oak, log grade F_1, with lumber-grade yields of 15.2 percent FAS, 11.5 percent SEL, 30.5 percent No. 1C, 23.5 percent No. 2C, 6.5 percent No. 3A and 12.8 percent No. 3B and the price relatives as shown in Table 1 for chestnut oak, the Q.I. calculation appears as:

$$\begin{aligned} \text{Q.I.} &= (.152 \times 1.90) + (.115 \times 1.81) + \\ &\quad (.305 \times 1.00) + (.235 \times 0.68) + \\ &\quad (.065 \times 0.59) + (.128 \times 0.40) \\ \text{Q.I.} &= 1.051 \end{aligned}$$

Log Q.I.'s were computed for each species and diameter for log grades F_1, F_2, and F_3 (Appendix, tables 7 to 12). For log classes below these grades, lumber-grade yields were not available and an arbitrary quality index of 0.400 was used. This arbitrary Q.I. was used because Trimble and Mendel found, in the absence of data on lumber-grade yields, a Q.I. of 0.400 was representative for this quality of logs regardless of species (Trimble and Mendel 1969).

DEVELOPMENT OF Q.I. LOG VALUES

The usefulness of log-quality indexes is well demonstrated when it is necessary to determine log values. All that is needed are the Q.I.'s for a given species, grade and diameter of log (Appendix), and the current No. 1 Common lumber price. For this study the average 1962 *Hardwood Market Report* prices for 4/4 No. 1 Common plain sawn lumber for each species was used. This year was selected in order to compare Q.I. values with actual values received by the study mills during this year. The average *Hardwood Market Report* prices were:

Red oak Black oak Scarlet oak	$105/M bd. ft.
White oak Chestnut oak	$110/M bd. ft.
Yellow-poplar	$130/M bd. ft.

Assume we wish to determine the lumber-product value of the previously used sample log, i.e., the 16-inch diameter chestnut oak grade F_1, whose log quality index was calculated as 1.051. All that is necessary is to multiply the Q.I. (1.051) times the 1962 price of No. 1 Common lumber ($110/M bd. ft.). Thus the Q.I. lumber value for this log would be (1.051 × $110/M) = $115.61/M bd. ft.

DEVELOPMENT OF COMMERCIAL SAWLOG VALUES

The commercial sawlog product values used in this analysis were developed from the previously mentioned study of seven sawmills located in southeastern Ohio and eastern Kentucky. At these mills red oak, black oak, scarlet oak, chestnut oak, white oak, and yellow-poplar logs were graded according to the specifications for U.S. Forest Service Factory Grades F_1, F_2, and F_3, construction and local use classes, and cull logs (table 2). Cull logs are those logs not meeting the specifications for the above grades and classes.

Table 2.—*Distribution of sawlogs used in analysis, by species and log grade or class*

Species	Log Grade No. 1	Log Grade No. 2	Log Grade No. 3	Construction and local use	Cull logs	Total
Red oak	19	20	9	2	5	55
Black oak	28	63	59	27	30	207
Scarlet oak	31	29	55	40	48	203
White oak	9	25	39	14	22	109
Chestnut oak	34	64	58	3	18	177
Yellow-poplar	82	206	258	147	158	851
Total	203	407	478	233	281	1,602

Each log was numbered and sawed into products following the regular sawing methods of the sawmill. This provided a representative estimate of sawlog product yields from regional commercial operations. Only lumber, timbers and similar products were included as sawlog product yield. The log products such as sawdust, chips, and slabs were excluded.

After a log was cut, all boards were graded by a qualified NHLA lumber inspector and the volume determined for each of the boards and other cut products. The value of each of these products from the log was determined by multiplying its volume by the price received by the study mill, f.o.b. mill. The sum of these values gave the commercial product value of the sawlog. Because of the limited data for some species and diameter classes, the log-product values for construction and local use log classes were combined.

HOW THE COMPARATIVE ANALYSIS WAS MADE

Ratios were used to measure and compare the independently developed sawmill log-product values with the Q.I. log-product

Table 3.—*Quality Index-commercial sawmill log product value ratios for scarlet oak, Log Grade No. 1, by diameter class*

Log d.i.b. (in.)	No. logs	Sawmill log product volume (bd. ft.)	Sawmill log product value (dollars)	Quality index	Q.I. log value[1] ($/M bd. ft.)	Q.I. log value (dollars)	Ratio sawmill/Q.I. log values
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
13	7	665	67.70	.964	101.22	67.31	1.006
14	3	293	30.53	.985	103.42	30.30	1.008
15	5	589	61.50	1.003	105.32	62.03	0.991
16	5	630	71.30	1.023	107.41	67.67	1.054
17	2	317	37.60	1.043	109.52	34.72	1.083
18	2	373	36.80	1.063	111.61	41.63	0.884
20	4	942	108.82	1.102	115.71	109.00	0.998
22	1	186	17.20	1.138	119.49	22.23	0.774
23	2	447	33.30	1.153	121.07	54.12	0.615
Total	31	4,442	464.75	—	—	489.00	0.950

[1] Value derived by multiplying Q. I. by No. 1 Common lumber price.

values. Quality index and commercial sawlog product values were determined for each log to develop the value ratios, as presented in table 3 for log grade No. 1 scarlet oak.

The following methods were used in calculating these values:

a. Columns 1, 2, 3 and 4 show the log diameter class, number of logs, volume of log products, and total log product value derived from the sawmill study of scarlet oak, grade No. 1 sawlogs that were sawn and sold.

b. Column 5 is the quality index for scarlet oak, log grade 1 by diameter class as derived from table 9 in the Appendix.

c. Column 6, Q.I. log value/M bd. ft., was computed by multiplying the average 1962 *Hardwood Market Report* price for No. 1 Common plain sawn scarlet oak lumber by the Q.I. (column 5). For example, to determine the Q.I. log-product value/M bd. ft. for 13-inch logs, the Q.I. was multipled by the 1962 price of No. 1 Common scarlet oak lumber (.964 × $105.00 = $101.22).

d. To determine the Q.I. log value of the sawmill study sawlogs, the sawmill log-product volume (column 3) was multiplied by the Q.I. unit value (column 6). For the 13-inch class this was .665 × $101.22 = $67.31 and was recorded in column 7.

e. The ratio of commerical sawmill/Q.I. log-product values (column 8) was computed by dividing the sawmill log-product value (column 4) by the Q.I. log value (column 7). For 13-inch logs this was $67.70/$67.31 = 1.006. Expressed in percent, the commercial sawmill log value of logs in this class was 0.6 percent greater than the computed quality index value for the same log diameter class. A value ratio, as in the 15-inch class, of 0.991 means that the commercial sawmill log-product values were below that computed by the quality index method by 0.9 percent.

Likewise, a value ratio of 1.000 would mean there was no difference in the commercial sawmill and computed quality index values for that group of logs. Value ratios, for each species by log grade and diameter class, are shown in the Appendix, tables 13-18.

It should be stressed that ratios of commercial sawlog and Q.I. sawlog values not only differ from mill to mill, but will change as the price relationships change between lumber and other products. These ratios should be checked periodically to determine whether they reflect current prices and mill sawing methods. Such checking could be accomplished by using a small sample of logs to determine the consistency of the ratios.

Results of Analysis

For all species analyzed in log grade No. 1 and No. 2 the commercial sawlog product values on the average were respectively 4.9 percent less and 7.3 percent greater than those predicted by the quality index for the same logs (table 4).

Table 4.—*Ratio of commercial sawlog and quality index sawlog product values, by species and Forest Service log grades and classes*

Species	Log Grade No. 1	Log Grade No. 2	Log Grade No. 3	Construction and local use	Cull logs	Construction, local use, and cull logs
Red oak	.966	1.227	1.317	1.531	1.810	1.711
Black oak	.884	1.163	1.151	1.670	1.392	1.534
Scarlet oak	.950	1.068	1.153	1.537	1.451	1.485
White oak	.766	1.056	1.057	1.338	1.400	1.371
Chestnut oak	1.012	1.293	1.233	1.847	1.724	1.745
Yellow-poplar	.956	.991	1.085	1.518	1.487	1.504
All species ave.	.951	1.073	1.119	1.533	1.483	1.507

There are two generalizations of significance concerning grade No. 1 and No. 2 logs: (1) sawmill operators in the region studied tend to saw logs into products whose value is within 10 percent, plus or minus, of that predicted by the quality index, (2) the quality-index method based on 4/4 grade lumber prices was a reliable tool to predict grade No. 1 and No. 2 log-product values in 1962.

The product value ratios of table 4 for log grades below grade

No. 2 indicate that sawmill operators convert their logs into (1) products of greater value than the grade lumber market would return and/or (2) obtained greater yields in the higher lumber grades than that obtained in the studies used for developing the quality index, or (3) sold their grade lumber in markets paying higher prices than quoted in the Hardwood Market Report. For example, grade No. 3 log-product values at commercial sawmills are almost 12 percent greater than the quality index predicted and for the lower log classes—construction, local use and culls—about 50 percent greater than the Q.I. predicted product value. Thus, if the Q.I. method based on 4/4 grade lumber yields and prices is used, adjustments must be made on a local basis to compensate for under-valuation of some log grades and classes by the Q.I. method.

The differences between Q.I. values and actual sawmill log product values were rather consistent throughout all species for most log grades. Also, the results indicate that size class (log diameter) does not significantly influence the value ratio. There was no consistent trend for any species from higher to lower or lower to higher values as size class changed. Statistical tests were also made to determine the adequacy of the sample log data. It was found that for accurate estimates of the value ratios, 4 to 8 sample logs for each diameter class and log quality class are required to maintain the standard error at the 5 percent level.

VALUE ADJUSTMENTS

We have indicated that the value differences found in the analysis are primarily related to different product yields or differences in product value in excess of that reported in the Hardwood Market Report.

Recovery in the higher lumber grades was a cause for value differences for some species and log grades or classes. Table 5 shows that one of the sawmills in the study recovered 20 percent more No. 1 Common and better lumber than the curved recovery data indicated for chestnut oak log grade No. 2.

Table 5.—Comparison of computed Q.I. and actual sawmill log product values for chestnut oak, Log Grade No. 2, at a commercial sawmill

Log d.i.b. (in.)	No. logs	Log volume (bd. ft.)	C.S. log value[1] $	Q.I. log value[2] $	Percent yield No. 1C & btr.		Percent value No. 1C & btr.		Percent yield 2C & below		Percent value 2C & below		Percent value other products		Percent yield other products	
					C.S.	Q.I.	C.S.	Q.I.	C.S.	Q.I.	C.S.	Q.I.	C.S.	Q.I.	C.S.	Q.I.
11	10	587	56.77	43.58	35	22	46	35	22	78	20	65	43	—	34	—
12	9	476	77.29	35.50	26	22	45	36	28	78	21	64	46	—	34	—
13	6	501	47.06	37.64	27	23	38	36	17	77	15	64	56	—	47	—
14	5	439	50.29	33.18	50	23	66	37	14	77	10	63	36	—	24	—
16	9	1,078	120.13	83.01	50	24	64	38	19	76	14	62	31	—	22	—
17	4	363	40.23	28.23	56	24	69	39	24	76	18	61	20	—	13	—
18	1	167	20.29	13.32	64	26	76	49	13	74	9	51	23	—	15	—
Average (percent)			—	—	43	23	56	37	20	77	16	63	37	—	28	—

[1] C.S.—Commercial sawmill A log product value

[2] Q.I.—Quality Index product value

The cause for the lower Q.I. values is related to the basic recovery data used in computing the Q.I. log values for this species. Using the Q.I. method, table 5 shows the average percent No. 2 Common and lower lumber grades recovered was 77 percent of the total yield and 63 percent of the total product value. On the other hand, commercial sawmill operations show only 20 percent of the yield and 16 percent of the value in these grades. The remaining yield and value at this commercial sawmill was in other products such as blocking, skids, barn timbers, bridge timbers, etc. This is characteristic of sawmill operations in the Ohio-Kentucky area.

These mills generally saw the low quality portion of a log (especially in the oak species) and the entire log in lower quality classes into products other than grade lumber. These products provide a greater return than grade lumber and are more readily marketable. Table 4 shows that for the chestnut oak this product differentiation starts in grade No. 3 logs and increases as the log quality is reduced.

Inasmuch as multi-product standards have not been developed, the above recovery and value differences point out the need for value adjustments when using the Q.I. method. Log evaluators must be alert to species and product mix variation by locality and region and make Q.I. value adjustments accordingly. Although we have emphasized the need for adjusting Q.I. log values, we must at the same time recognize that when the objective product mix is heavy to grade lumber, value adjustments may be unnecessary.

Table 6 shows that the Q.I. estimate of product yield and value for yellow-poplar, log grade No. 2 was consistent with that received by commercial sawmill operations. In this case, only six percent of the yield, representing four percent of the value, was processed into products other than grade lumber by the sawmills studied.

Published log yield data for log classes by lumber grade for logs not meeting F_1, F_2, F_3 standards is not available. As indicated earlier an arbitrary Q.I. of .400 was selected for these log classes. It is apparent from the analysis that the Q.I. must be adjusted

Table 6.—Comparison of computed Q.I. and actual commercial sawmill log values for yellow-poplar, Log Grade No. 2

Log d.i.b. (in.)	No. logs	Log volume (bd. ft.)	C.S. log value[1] $	Q.I. log value[2] $	Percent yield No. 1C & btr.		Percent value No. 1C & btr.		Percent yield 2C & below		Percent value 2C & below		Percent yield other products		Percent valu other products	
					C.S.	Q.I.	C.S.	Q.I.	C.S.	Q.I.	C.S.	Q.I.	C.S.	Q.I.	C.S.	Q.I.
11	25	1,609	150.67	155.62	37	42	46	59	55	58	49	41	8	—	5	—
13	25	1,969	200.31	193.51	41	42	50	60	50	58	44	40	9	—	6	—
12	40	2,576	243.58	251.50	46	43	55	60	49	57	42	40	5	—	3	—
14	25	2,185	222.17	217.30	45	44	58	61	51	56	39	39	4	—	3	—
15	24	2,337	229.09	235.45	38	46	48	62	55	54	48	38	7	—	4	—
16	18	2,194	228.63	224.18	51	47	61	64	45	53	36	36	4	—	3	—
17	14	1,794	184.65	185.64	55	49	67	65	42	51	31	35	3	—	2	—
18	10	1,306	119.73	136.67	57	50	63	65	39	50	35	35	4	—	2	—
19	10	1,577	159.85	166.26	58	51	66	66	38	49	32	34	4	—	2	—
20	4	573	65.77	60.86	67	52	78	67	31	48	20	33	2	—	2	—
21	1	152	13.99	16.26	57	53	58	68	43	47	42	32	—	—	—	—
22	6	1,130	109.88	121.93	63	54	72	69	25	46	20	31	12	—	8	—
23	2	379	63.05	41.24	87	55	94	70	8	45	14	30	5	—	2	—
24	2	521	53.57	57.10	78	56	84	71	20	44	15	29	2	—	1	—
Average (percent)			—	—	50	49	60	63	44	51	36	37	6	—	4	—

[1] C.S.—Commercial sawmill.
[2] Q.I.—Quality Index.

upward for these lower quality classes. Table 4 shows that the value difference was rather consistent for the lower log quality classes, regardless of species. This would indicate that a Q.I., based on 4/4 grade lumber recovery and values, should be adjusted upward for these log quality classes.

Until more realistic lumber recovery data becomes available for computing the Q.I. log values, an adjustment of 40-50 percent upward would appear to be valid for construction, local use, and cull logs.

Adjusting Q.I. Log Values

This report contains all the necessary information for finding the estimated product value of a log for a mill that has processing procedures and price relationships similar to the mills used in this study. The only outside information needed is a reliable No. 1 Common lumber price. For example, assume a buyer wants to know the value of products he can expect to saw from a 13-inch diameter, 14-foot long scarlet oak grade No. 3 log when the current selling price of 4/4 No. 1 Common red oak lumber is $130/M bd. ft. The volume of this log is 100 board feet (Int. 1/4-inch rule), and its Q.I. value given in table 9, Appendix is .620. Substituting these values in the Q.I. log-product value formula:

$$\text{Q.I. log-product value} = \frac{(\text{Q.I.}) \times (\text{No. 1 Common lumber price}) \times (\text{bd. ft. volume of log})}{1000}$$

$$= (.620) \times (\$130) \times (.100)$$

$$= \$8.06$$

This $8.06 is what he can expect to receive from this log if it is sawn into 4/4 grade lumber. However, usually such a low quality log is sawn into grade lumber and other products. This requires an adjustment in the Q.I. log-product value if it is to represent the value of the various products which can be sawn from this log. The adjustment is made by substituting the log value ratio (Appendix, table 15) of this log (1.344) in the formula:

$$\begin{aligned}\text{Adjusted Q.I. log-product value} &= (\text{Q.I. log-product value}) \\ &\quad \times (\text{log value ratio}) \\ &= (\$8.06) \times (1.344) \\ &= \$10.83\end{aligned}$$

The buyer can expect to receive $10.83 from the products sawn from this 13-inch, 14-foot scarlet oak grade No. 3 log.

CONCLUSIONS

This analysis shows that the quality-index method of log valuation will provide a consistent estimate of log-product values when grade lumber is produced. However, where sawmill practices and product mix objectives are other than producing grade lumber, adjustments in log-product value estimates must be made. These adjustments have been found to be of greater consequence in the lower quality logs (log grade No. 3 and below), which mill operators generally process into products of higher value than low-grade lumber.

Because of the differences in recovery it is recommended that when regional or national lumber grade yields for a given species are used to determine log values by the Q.I. method, local adjustments should be made to bring values more closely in line with reality. The methods outlined here can be used to develop adjustment ratios for regions and mills outside the area studied. Samples of more than four logs for each species-log grade cell need to be studied to give reliable results.

The methods and analysis used here can serve as a guide for adjusting log values; however, the real need is a multi-product grading system. With such a system, Q.I.'s could be developed for all product grades and eliminate the need for adjusting the Q.I. values.

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APPENDIX

Table 7.—*Log-quality index for red oak by log grade or class and size class*[1]

Log d.i.b. inches	Quality index			
	Log Grade No. 1	Log Grade No. 2	Log Grade No. 3	Construction, local use, and cull classes
8	—	—	.437	.400
9	—	—	.437	.400
10	—	.694	.439	.400
11	—	.702	.442	.400
12	—	.714	.445	.400
13	0.992	.731	.447	.400
14	1.080	.748	.448	.400
15	1.118	.766	.454	.400
16	1.147	.773	.462	.400
17	1.160	.773	.474	.400
18	1.165	.776	.493	.400
19	1.165	.778	.514	.400
20	1.165	.782	.543	.400
21	1.165	.784	.572	.400
22	1.166	.787	.606	.400
23	1.169	.792	.645	.400
24	1.172	.799	.686	.400
25	1.175	—	.729	.400
26	1.184	—	—	.400
27	1.195	—	—	.400
28	1.209	—	—	.400
29	1.223	—	—	.400
30	1.237	—	—	.400

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[1] By hand-curving lumber grade yield data from Res. Paper FPL-63 and 1962-1966 lumber prices from *Hardwood Market Report.*

Table 8.—*Log-quality index for black oak by log grade or class and size class*[1]

Log d.i.b. inches	Quality index			
	Log Grade No. 1	Log Grade No. 2	Log Grade No. 3	Construction, local use, and cull classes
8	—	—	.501	.400
9	—	—	.521	.400
10	—	.687	.539	.400
11	—	.690	.557	.400
12	—	.692	.575	.400
13	1.043	.695	.593	.400
14	1.051	.704	.612	.400
15	1.065	.713	.629	.400
16	1.079	.724	.646	.400
17	1.098	.733	.663	.400
18	1.118	.747	.678	.400
19	1.140	.762	.697	.400
20	1.159	.780	.714	.400
21	1.184	.799	—	.400
22	1.205	.819[2]	—	.400
23	1.230	.840[2]	—	.400
24	1.256	.862[2]	—	.400
25	1.280	.885[2]	—	.400
26	1.304	.904[2]	—	.400
27	1.329	.929[2]	—	.400

[1] By hand-curving lumber grade yield data from Res. Paper FPL-63 and 1962-1966 lumber prices from *Hardwood Market Report.*

[2] Extrapolated from curved indexes. Yield data for Q. I. development not available.

Table 9.—Log-quality index for scarlet oak by log grade or class and size class[1]

Log d.i.b. inches	Quality index			
	Log Grade No. 1	Log Grade No. 2	Log Grade No. 3	Construction, local use, and cull classes
8	—	—	.523	.400
9	—	—	.539	.400
10	—	—	.557	.400
11	—	.771	.578	.400
12	—	.775	.598	.400
13	.964	.782	.620	.400
14	.985	.794	.641	.400
15	1.003	.806	.659	.400
16	1.023	.818	.679	.400
17	1.043	.831	.695	.400
18	1.063	.845	.711	.400
19	1.081	.860	.727	.400
20	1.102	.874	.743	.400
21	1.119	.888	.759[2]	.400
22	1.138	.902	—	.400
23	1.153	.915	—	.400

[1] By hand-curving lumber grade yield data from Res. Paper FPL-63 and 1962-1966 lumber prices from *Hardwood Market Report.*

[2] Extrapolated from curved indexes. Yield data for Q. I. development not available.

Table 10.—*Log-quality index for white oak by log grade or class and size class*[1]

Log d.i.b. inches	Quality index			
	Log Grade No. 1	Log Grade No. 2	Log Grade No. 3	Construction, local use, and cull classes
8	—	—	.518	.400
9	—	—	.531	.400
10	—	.709	.543	.400
11	—	.730	.558	.400
12	—	.746	.572	.400
13	1.039	.764	.586	.400
14	1.096	.783	.600	.400
15	1.145	.803	.613	.400
16	1.187	.820	.629	.400
17	1.228	.841	.650	.400
18	1.255	.857	.675	.400
19	1.277	.872	.702	.400
20	1.289	.887	.726	.400
21	1.310	.906	.753	.400
22	1.336	.925	.783	.400
23	1.365	.945	.809	.400
24	1.402	.968	.844	.400
25	1.442	.991	.872	.400
26	—	1.017	.900	.400
27	—	1.043	—	.400
28	—	1.084	—	.400

[1] By hand-curving lumber grade yield data from Res. Paper FPL-63 and 1962-1966 lumber prices from *Hardwood Market Report.*

Table 11.—*Log-quality index for chestnut oak by log grade or class and size class*[1]

Log d.i.b. inches	Quality index			
	Log Grade No. 1	Log Grade No. 2	Log Grade No. 3	Construction, local use, and cull classes
8	—	—	.521	.400
9	—	—	.545	.400
10	—	.671	.563	.400
11	—	.675	.581	.400
12	—	.678	.594	.400
13	1.033	.683	.599	.400
14	1.037	.687	.601	.400
15	1.045	.693	.602	.400
16	1.051	.700	.603	.400
17	1.059	.707	.604	.400
18	1.065	.725	.605	.400
19	1.069	.743	.605	.400
20	1.078	.760	.606	.400
21	1.085	.782	.608	.400
22	1.091	.790	.609	.400
23	—	.797	.612	.400
24	—	.806	.616	.400
25	—	.820	.622	.400
26	—	.824	.626	.400
27	—	.833	.632	.400
28	—	.843	.638	.400
29	—	.857	—	.400
30	—	.862	—	.400
31	—	.870	—	.400

[1] By hand-curving lumber grade yield data from Res. Paper FPL-63 and 1962-1966 lumber prices from *Hardwood Market Report.*

Table 12.—*Log-quality index for yellow-poplar by log grade or class and size class*[1]

Log d.i.b. inches	Quality index			
	Log Grade No. 1	Log Grade No. 2	Log Grade No. 3	Construction, local use, and cull classes
8	—	—	.524	.400
9	—	—	.539	.400
10	—	.743	.553	.400
11	—	.744	.568	.400
12	—	.751	.583	.400
13	.895	.756	.600	.400
14	.915	.765	.615	.400
15	.933	.775	.630	.400
16	.947	.786	.645	.400
17	.963	.796	.659	.400
18	.977	.805	.672	.400
19	.991	.811	.688	.400
20	1.001	.817	.703[2]	.400
21	1.014	.823	.718[2]	.400
22	1.024	.830	.733[2]	.400
23	1.033	.837	.748[2]	.400
24	1.045	.843	.763[2]	.400
25	1.055	.850	—	.400
26	1.063	—	—	.400
27	1.071	—	—	.400
28	1.075	—	—	.400
29	1.078	—	—	.400
30	1.079	—	—	.400

[1] By hand-curving lumber grade yield data from Res. Paper FPL-63 and 1962-1966 lumber prices from *Hardwood Market Report.*

[2] Extrapolated from curved indexes. Yield data for Q. I. development not available.

Table 13.—*Ratio of commercial sawlog and Q. I. sawlog values for red oak*

Log d.i.b.	Log Grade No. 1		Log Grade No. 2		Log Grade No. 3		Construction and local use logs		Cull logs		Construction, local use, and cull classes	
inches	No. logs	Ratio	No. logs	Ratio	No. logs	Ratio	No. logs	Ratio	No. logs	Ratio	No. logs	Ratio
10					1	1.086	—	—	—	—	—	—
11			1	1.115	—	—	—	—	—	—	—	—
12			4	1.332	1	1.724	—	—	1	2.200	1	2.200
13	2	1.028	2	1.572	1	1.153	—	—	1	1.894	1	1.894
14	2	1.029	2	1.058	—	—	1	1.533	2	1.518	3	1.516
15	1	0.577	1	1.249	—	—	—	—	1	2.241	1	2.241
16	2	1.075	1	1.420	—	—	1	1.519	—	—	1	1.519
17	1	0.983	2	1.345	2	1.351	—	—	—	—	—	—
18	3	1.053	1	0.815	2	1.534	—	—	—	—	—	—
19	3	0.988	4	1.264	—	—	—	—	—	—	—	—
20	2	1.085	1	1.103	—	—	—	—	—	—	—	—
21	1	1.187	—	—	—	—	—	—	—	—	—	—
22	1	0.854	—	—	—	—	—	—	—	—	—	—
23	—	—	—	—	—	—	—	—	—	—	—	—
24	—	—	—	—	2	1.220	—	—	—	—	—	—
25	—	—	1	1.099	—	—	—	—	—	—	—	—
26	—	—	—	—	—	—	—	—	—	—	—	—
27	—	—	—	—	—	—	—	—	—	—	—	—
28	—	—	—	—	—	—	—	—	—	—	—	—
29	—	—	—	—	—	—	—	—	—	—	—	—
30	1	0.609	—	—	—	—	—	—	—	—	—	—
Total	19		20		9		2		5		7	
Log grade ratio		0.966		1.227		1.317		1.531		1.810		1.711

Table 14.—*Ratio of commercial sawlog and Q. I. sawlog values for black oak*

Log d.i.b.	Log Grade No. 1		Log Grade No. 2		Log Grade No. 3		Construction and local use logs		Cull logs		Construction, local use, and cull classes	
inches	No. logs	Ratio	No. logs	Ratio	No. logs	Ratio	No. logs	Ratio	No. logs	Ratio	No. logs	Ratio
6									1	1.786	1	1.786
7									2	1.609	2	1.609
8					—	—	—	—	—	—	—	—
9					3	1.141	4	1.379	3	1.469	7	1.424
10					4	1.116	7	1.657	5	1.383	12	1.561
11			6	0.939	10	1.245	2	1.224	6	1.241	8	1.238
12			12	1.019	12	1.083	2	1.835	2	1.189	4	1.519
13	3	0.850	15	1.143	8	1.065	6	1.553	4	1.360	10	1.474
14	6	0.844	8	1.102	8	0.999	1	1.470	1	1.189	2	1.343
15	6	0.911	6	1.196	6	1.310	1	1.456	2	1.609	3	1.563
16	5	0.853	6	1.332	4	1.174	1	1.856	2	1.596	3	1.659
17	5	0.926	3	1.137	2	1.202	1	1.337	2	1.221	3	1.254
18	1	0.908	4	1.377	—	—	1	2.130	—	—	1	2.130
19	1	0.904	1	1.337	1	1.128	—	—	—	—	—	—
20	—	—	—	—	1	1.381	—	—	—	—	—	—
21	—	—	1	1.378	—	—	—	—	—	—	—	—
22	—	—	—	—	—	—	1	2.248	—	—	1	2.248
23	1	0.857	—	—	—	—	—	—	—	—	—	—
24	—	—	—	—	—	—	—	—	—	—	—	—
25	—	—	—	—	—	—	—	—	—	—	—	—
26	—	—	—	—	—	—	—	—	—	—	—	—
27	—	—	1	0.898	—	—	—	—	—	—	—	—
Total	28		63		59		27		30		57	
Log grade ratio		0.884		1.163		1.151		1.670		1.392		1.534

Table 15.—*Ratio of commercial sawlog and Q. I. sawlog values for scarlet oak*

Log d.i.b.	Log Grade No. 1		Log Grade No. 2		Log Grade No. 3		Construction and local use logs		Cull logs		Construction, local use, and cull classes	
inches	No. logs	Ratio	No. logs	Ratio	No. logs	Ratio	No. logs	Ratio	No. logs	Ratio	No. logs	Ratio
8					—	—	—	—	4	1.533	4	1.533
9					1	1.336	—	—	4	1.588	4	1.588
10					2	1.561	6	1.668	7	1.446	13	1.561
11			1	0.958	2	1.019	10	1.514	4	1.581	14	1.538
12			4	1.060	12	1.105	6	1.593	11	1.426	17	1.481
13	7	1.006	4	1.134	8	1.344	8	1.570	7	1.457	15	1.526
14	3	1.008	6	1.127	8	1.159	6	1.491	1	1.494	7	1.492
15	5	0.991	4	1.117	2	1.074	1	1.405	4	1.377	5	1.385
16	5	1.054	3	1.199	7	1.159	3	1.392	2	1.246	5	1.335
17	2	1.083	3	1.065	5	1.064	—	—	2	1.407	2	1.407
18	2	0.884	—	—	5	1.069	—	—	1	1.481	1	1.481
19	—	—	—	—	2	1.069	—	—	—	—	—	—
20	4	0.998	1	1.292	—	—	—	—	1	1.371	1	1.371
21	—	—	1	1.088	1	1.465	—	—	—	—	—	—
22	1	0.774	1	0.528	—	—	—	—	—	—	—	—
23	2	0.615	1	0.964	—	—	—	—	—	—	—	—
Total	31		29		55		40		48		88	
Log grade ratio		0.950		1.068		1.153		1.537		1.451		1.485

Table 16.—*Ratio of commercial sawlog and Q. I. sawlog values for white oak*

Log d.i.b. inches	Log Grade No. 1		Log Grade No. 2		Log Grade No. 3		Construction and local use logs		Cull logs		Construction, local use, and cull classes	
	No. logs	Ratio	No. logs	Ratio	No. logs	Ratio	No. logs	Ratio	No. logs	Ratio	No. logs	Ratio
7									1	1.082	1	1.082
8					2	1.136	1	1.133	2	1.446	3	1.333
9					3	1.267	1	1.287	4	1.450	5	1.426
10					3	1.263	2	1.073	3	1.246	5	1.172
11			2	0.819	10	1.098	4	1.210	6	1.384	10	1.315
12			7	1.035	6	1.091	3	1.550	1	1.137	4	1.455
13	3	0.811	2	0.862	6	1.003	1	1.227	3	1.336	4	1.307
14	3	0.695	8	0.927	3	1.190	—	—	—	—	—	—
15	1	0.500	3	1.136	3	0.884	2	1.413	1	2.099	3	1.631
16	—	—	—	—	1	1.243	—	—	1	1.137	1	1.137
17	—	—	1	1.444	—	—	—	—	—	—	—	—
18	2	0.868	2	1.316	1	0.776	—	—	—	—	—	—
19	—	—	—	—	—	—	—	—	—	—	—	—
20	—	—	—	—	—	—	—	—	—	—	—	—
21	—	—	—	—	—	—	—	—	—	—	—	—
22	—	—	—	—	—	—	—	—	—	—	—	—
23	—	—	—	—	1	0.883	—	—	—	—	—	—
Total	9		25		39		14		22		36	
Log grade ratio		0.766		1.056		1.057		1.338		1.400		1.371

Table 17.—*Ratio of commercial sawlog and Q. I. sawlog values for chestnut oak*

Log d.i.b.	Log Grade No. 1		Log Grade No. 2		Log Grade No. 3		Construction and local use logs		Cull logs		Construction, local use, and cull classes	
inches	No. logs	Ratio	No. logs	Ratio	No. logs	Ratio	No. logs	Ratio	No. logs	Ratio	No. logs	Ratio
8					3	1.354	—	—	2	1.671	2	1.671
9					7	1.389	—	—	7	1.692	7	1.692
10					13	1.238	2	1.683	1	1.591	3	1.658
11			14	1.240	8	1.255	—	—	4	1.535	4	1.535
12			14	1.244	6	1.204	1	2.119	2	1.515	3	1.706
13	9	1.081	10	1.189	5	1.104	—	—	—	—	—	—
14	6	1.019	9	1.204	6	1.290	—	—	—	—	—	—
15	6	1.046	1	0.881	1	1.670	—	—	1	1.161	1	1.161
16	4	1.001	9	1.443	3	1.246	—	—	—	—	—	—
17	6	0.963	4	1.421	2	1.184	—	—	—	—	—	—
18	—	—	1	1.522	2	1.460	—	—	1	2.899	1	2.899
19	3	0.904	1	1.677	2	1.011	—	—	—	—	—	—
20	—	—	1	1.144	—	—	—	—	—	—	—	—
Total	34		64		58		3		18		21	
Log grade ratio		1.012		1.293		1.233		1.847		1.724		1.745

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A FURROW-SEEDER for the Northeast

by Raymond E. Graber
and Donald F. Thompson

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FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
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A
FURROW-SEEDER
for the Northeast

INTRODUCTION

ON MANY acres of unproductive wild lands in the Northeast, planting or seeding is needed to establish new stands of conifers. However, planting is very expensive on these lands, and direct seeding has often failed.

Our research on direct seeding over the past several years has shown that mineral soil seedbeds and shade from an existing overstory will provide a microenvironment favorable for germination and seedling survival *(McConkey 1964, Graber 1965 and 1968).* We have also found that the protective (endrin-arasan) coating used in the South to prevent destruction of seed by birds and small mammals does not offer adequate protection under northern conditions unless the seed is covered with soil *(Graber 1969).*

Furrow-seeding techniques seem to offer the best means of providing these desired conditions at reasonable cost *(Croker 1967).* A tractor-drawn furrow-seeder prepares a mineral seedbed, sows and covers the seed, and can be maneuvered so as to leave some existing vegetation between furrows for shade.

Since no commercial equipment was suitable for use under typical northeastern brushland conditions, we adapted existing equipment to suit our needs. From a fireline plow and a beet planter, we devised a furrow-seeder. We tested it over a wide range of site conditions to evaluate its operational efficiency and to determine the stocking of red and white pine seedlings that were established through its use (fig. 1).

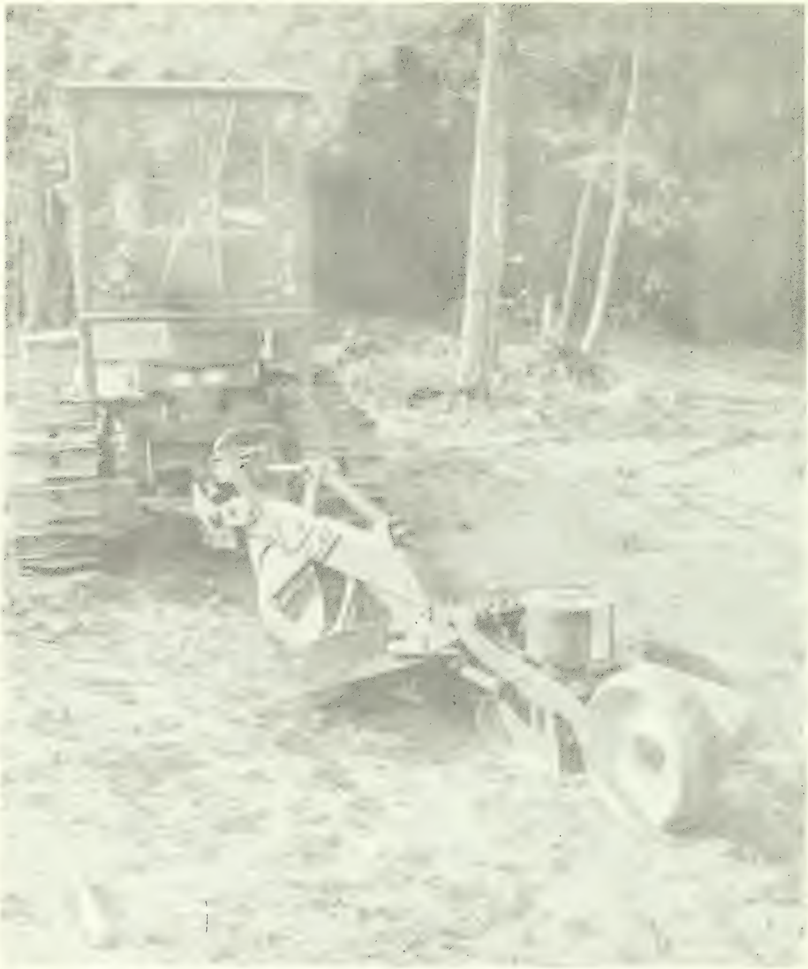

Figure 1.—A furrow-seeder, devised from existing equipment, was used successfully over a wide range of Northeastern soils, vegetation, and topography.

We found that the unit performed satisfactorily and promoted favorable seedling emergence, survival, and stocking at all locations tested. Direct seeding with this equipment costs between $7 and $15 per acre. We believe that this furrow-seeder will provide a reliable means of establishing pine on lands now occupied by brush or low-quality hardwoods—and at about one-third the cost of planting nursery stock.

EQUIPMENT

The equipment used and modifications required have been described in detail previously *(Graber and Thompson 1967)*. The new furrow-seeder consists of a modified International Harvester beet planter, coupled behind a fireline plow (Sieco C154). The rig is pulled by a small crawler tractor (John Deere 1010).[1] The tractor and fireline plow had previously been found capable of producing an excellent mineral-soil seedbed at low cost, and it worked well on the stony, wooded lands commonly encountered in the Northeast.

Modifications made to the seeder included: the use of an oversized drive wheel and a runner opener with a steel ski on the bottom; a new free-floating mount that allowed the seeder to ride up over obstacles such as large stones, stumps, or logs; and general reworking and strengthening of the seeder unit at all points of strain.

METHODS

The furrow-seeder trials were conducted over a variety of field conditions in southwestern Maine, including dominant vegetation ranging from grass to sapling and small pole hardwoods; soil ranging from outwash sands to stony tills; and topography ranging from level land to 30-percent slopes (table 1). Two-acre plots of typical combinations of vegetation, soil, and topography were established at nine locations. At each location, 20 parallel furrows were plowed and seeded in the spring of 1967. The furrows were 400 feet long with a 12-foot interval from furrow center to furrow center.

This relatively wide spacing between furrows was necessary to allow the operator sufficient room to maneuver around obstacles on the more difficult plots. The interior 12 furrows at each location consisted of two six-furrow replications to allow a statistical

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[1] The furrow-seeder was developed and tested cooperatively by the Maine Forest Service and the Northeastern Forest Experiment Station, Forest Service, U. S. Department of Agriculture. Mention of a brand name does not imply endorsement by the Forest Service or the Department of Agriculture.

Table 1.—*Description of experimental plots*

Plot name	Dominant vegetation					Surface obstacles		Slope	Soil type
	Type	Mean basal area	Mean d.b.h.	Mean height	Stems/ acre	Stones 6 inches plus	Stumps and down trees		
		Square feet	*Inches*	*Feet*	*Number*	*Percent*[1]	*Percent*[1]	*Percent*	
Brandt field	Native and introduced grasses	—	—	—	—	0.6	—	0-8	Gloucester sandy loam
Smith field	Native and introduced grasses	—	—	—	—	5.9	—	0-8	Gloucester stony sandy loam
Ross brushland	Scrub oak[2]	16	0.6	6	5,520	0	0	0-6	Adams loamy sand
Ross brushy hillside	Scrub oak	26	.7	7	7,820	0	0	10-30	Adams loamy sand
Rosen woodland	Quaking aspen[3]	56	1.1	14	7,440	0	0	0-2	Ninigret sandy loam
Smith woodland	Gray birch,[4] paper birch[5]	14	1.7	18	860	3.2	0	0-3	Gloucester stony loam
Smith wooded hillside	Paper birch, black oak,[6] red maple[7]	27	2.0	21	1,020	2.6	3.8	10-20	Gloucester stony sandy loam
Nalf woodland	Red maple, black oak, gray birch	20	2.2	20	638	8.6	2.1	0-3	Paxton stony fine sandy loam
Bachand woodland	Black oak, paper birch, red maple	49	3.1	26	869	13.6	0	0-10	Sutton extremely stony fine sandy loam

[1] Percentage of surface area occupied by obstacles.

[2] *Quercus illicifolia* Wang.

[3] *Populus tremuloides* Michx.

[4] *Betula populifolia* Marsh.

[5] *B. papyrifera* Marsh.

[6] *Q. velutina* Lam.

[7] *Acer rubrum* L.

test of the location effect. The six-furrow replications were divided into two subplots of three furrows each, and to each was randomly assigned a species treatment of either red pine *(Pinus resinosa* Ait.) or white pine (*Pinus strobus* L.)

Seedling emergence, survival, and stocking observations were made at ten randomly selected sample points in each subplot. Seedling data at each sample point were collected on a 6-foot furrow segment that was divided into two 3-foot furrow segments or subpoints.

Analysis of variance was used to test the significance of the location and species effects. When these effects were significant, statistical comparisons among treatment means were made, using Duncan's *(1955)* new multiple-range test.

The site preparation (furrowing) and seeding were carried out in a continuous operation with the furrow-seeder. The seeds were dropped at uniform intervals (approximately 7 inches apart) into a narrow groove cut in the bottom of the furrow by the runner opener. The seed was then pressed into firm contact with the soil by the packing wheel and covered with loose soil by a chain dragged behind the packing wheel.

Before sowing, the white pine seed had been stratified 60 days at 40°F. to break dormancy. The seeds of both species were coated with arasan and endrin.

RESULTS & DISCUSSION

Furrow-Seeder Production

Detailed records of time required for furrow-seeding at each location were kept to provide a measure of productivity under each set of field conditions (table 2). These data are actual operating times on the study area, with no allowance for transportation, for unloading, for moving the equipment to the study area, or for rest breaks.

The effect of location on furrow-seeding time was highly significant (at the 1-percent level). Generally the results (table 2) were quite logical. The almost complete absence of stone at the first four locations listed made possible a significantly faster rate of furrow-seeding. The Brandt field was furrow-seeded very

Table 2.—*Furrow-seeder production, in minutes*

Location	Mean time[1] per 400-foot furrow	Calculated time/acre
Brandt field	1.66	15.1
Ross brushland	3.10	28.1
Ross brushy hillside	3.53	32.0
Rosen woodland	3.62	32.8
Smith field	4.43	40.2
Smith wooded hillside	4.55	41.3
Nalf woodland	5.06	45.9
Smith woodland	5.32	48.3
Bachand woodland	6.14	55.7

[1] Duncan's new multiple-range test. Means not connected by a vertical line differ significantly at the 5-percent level.

rapidly because of the gentle topography, excellent visibility, and the almost complete absence of any obstacles, eliminating any need to maneuver the tractor. This allowed the driver to shift into a high gear and operate at full throttle. The woody plant cover at the Ross and Rosen locations caused a signicant slowing of operations even in the absence of stone. The large amount of stone in the Smith field necessitated frequent maneuvering to avoid collisions, forcing the tractor operator to reduce his speed.

Further reductions in operating speed were necessary when both stone and overstory trees and other obstacles were encountered. The thicker the maze of all obstacles combined, the slower the furrow-seeding, simply because of the time required by the operator to pick a suitable path and maneuver the equipment past the obstacles.

Species composition and size of dominant vegetation caused differences in ease of movement of the equipment. Where the dominant plants were small, with a mean d.b.h. of 1 inch or less, species mattered little. Larger trees—especially species such as oak, maple, or birch—offered much more resistance. Ordinarily it was much quicker to bypass these trees than to push them aside. Soft brashy-wooded species, such as aspen, offered very little resistance, at least in the sizes encountered here.

The influence of slope on rate of furrow-seeding was obscured by other factors that had a greater bearing on operating efficiency. The Ross brushy hillside plot (20 to 30 percent slope) took slightly longer to furrow-seed than the adjacent Ross brushland plot (0 to 6 percent slope), as might be expected; but the differences were not significant. The reverse was true at the Smith locations, where the wooded hillside plot (10 to 20 percent slope) required significantly less time to furrow-seed than the adjacent woodland plot (0 to 3 percent slope). In spite of these contradictory results, a noticeable if unimportant reduction in production did occur, especially where the side slope exceeded 25 percent. It was necessary for the operator to exercise greater caution on these steep side slopes, which reduced production.

Degree of Seedbed Preparation

A rough measure of seedbed quality is the area of mineral soil exposed. After furrow-seeding, the furrow width was determined at 10 randomly selected points in each of the 12 study furrows at each location. The average width of each replication was then multiplied by the combined furrow length, 2,400 feet, to give area. These areas are given in table 3.

Table 3.—*Seedbed area*

Location	Mean area of mineral soil[1] per six 400-foot long furrows
	Square feet
Brandt field	7,440
Smith field	6,240
Ross brushland	6,240
Smith woodland	5,640
Smith wooded hillside	5,640
Ross brushy hillside	5,280
Rosen woodland	4,800
Nalf woodland	3,960
Bachand woodland	3,600

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[1] Duncan's new multiple-range test. Means not connected by a vertical line differ significantly at the 5-percent level.

The fireline plow cleared a furrow 6 inches deep and 38 inches wide under optimum conditions. Where stones, roots, stumps, and trees interfered, the furrow was both shallower and narrower; and, under very difficult conditions, a skip occurred.

Differences among the nine locations in the amount of mineral soil exposed were highly significant. Large amounts of mineral soil were exposed in the open fields and on the level Ross brushland tract. Where the equipment was operating on a side slope, there was a tendency for the turned-out furrow slice on the uphill side to fall back into the furrow. This falling-in of the furrow caused low ranking of the Ross brushy hillside tract.

Where furrow-seeding was difficult, as on the Nalf and Bachand tracts, the area of mineral soil seedbed was reduced. The results on the Bachand tract were poor because the soil was so stony that the plow was repeatedly forced out of the soil by subsurface stone, and frequently was lifted by the operator to avoid striking large visible stones. An additional difficulty on the Nalf tract was the presence of dense clumps of prostrate juniper (*Juniperus communis* L. var. *depressa* Purch), less than 3 feet high, that occurred in small openings. The juniper stems were very brittle and broke off, fouling the plow and causing it to ride up out of the ground. The results were a narrow furrow and occasional outright misses. It is likely that a V-blade mounted on the front of the tractor would have helped overcome this difficulty. A similar effect reduced the area of seedbed on the Rosen tract; there the soft and brashy aspen overstory was easily crushed by the tractor, but the tops of the trees broke off and collected in front of the plow, gradually lifting it out of the soil.

Clearing the brush-entangled plow was simple but time-consuming, so the tractor operator was instructed to continue plowing as long as the furrow width did not fall below a minimum of 1 foot. To clear the plow, the operator had only to lift it and the seeder off the ground and reverse the direction of travel. The crawler tracks would then catch the dragging brush and debris, pulling it free. Normally it was necessary to back the machine only 10 to 15 feet to completely clear it of entangling brush and debris.

Seedling Emergence

Seedling emergence as a percent of the viable seeds sown was high: the mean value was 73 percent. No significant differences in emergence were found among the nine locations or between the two species. This was partly because the seed was uniformly buried in a well-prepared mineral soil seedbed at all study locations. In addition, the amount and frequency of precipitation during May and June, when most of the seeds germinated and emerged, was generally favorable.

Though there was a wide range in environmental conditions due to differences in soil and vegetation, the effect on seedling emergence was not significant.

Seedling Survival

Seedling survival, as a percentage of the emerging seedlings living at the end of the first growing season, averaged 70.1 percent over the entire experiment. No significant differences existed among the nine locations included in this study. However, there was a significant difference (5-percent level) between species. Red pine seedling survival was 74.5 percent, while white pine survival was 67.0 percent. This reflects the better adaptation of red pine to the more exposed conditions during the first growing season.

At the end of the second growing season, the species differences were no longer significant. However, the influence of growing conditions (location) was significant at the 1-percent level. Second-year survival as a percentage of seedling emergence ranged from 75.0 to 38.2 percent at the nine locations under study (table 4).

Survival was very good at the Rosen location, primarily due to the high water table at this site, which reduced drought-related losses to one-half of those found on the study as a whole. The major reason for poor survival on the Bachand tract was the heavy losses caused by small mammals soon after seedling emergence, and later trampling by deer. Small mammals at this location caused 14 percent of all losses compared to less than 1 percent on the other locations. Mortality due to deer trampling was five times greater on the Bachand tract (9.5 vs. 1.9 percent) than on the

Table 4.—*Seedling survival at the end of the second growing season*

Location	Seedling survival[1] Percent of emerging seedlings
Rosen woodland	75.0
Ross brushy hillside	64.6
Smith wooded hillside	60.6
Smith woodland	57.0
Ross brushland	53.4
Brandt field	53.4
Nalf woodland	53.2
Smith field	51.8
Bachand woodland	38.2

[1] Duncan's new multiple-range test. Means not connected by a vertical line differ significantly at the 5-percent level.

study as a whole. This, coupled with a heavy litter fall, which caused many seedlings to smother, resulted in significantly poorer survival on the Bachand tract than on any other location.

The major cause of seedling mortality on all locations was drought. Most of these losses took place during and just after germination, before the seedlings became established. Approximately one-half of all seedlings killed during the first growing season died from this cause.

Stocking

A measure of seedling stocking provides a practical evaluation of the success of a seeding operation. Stocking is given as a percentage of 3-foot-long sample segments (subpoints) with one or more seedlings. At the end of the second growing season, average stocking was 70 percent. The effect of location was significant at the 1-percent level. Naturally, the ranking of locations from the best to the poorest was similar to the ranking under survival (table 5).

The Bachand tract was appreciably poorer than any of the other locations because of the seedling mortality discussed in the preceding section. It is our estimate that 50 percent or better stocking is adequate at the end of the second growing season.

This would mean that only the Bachand tract is in danger of a failure, and even here, the linear increment used to measure stocking has a great influence on the data. If a 6-foot furrow increment is used as the basic stocking unit, the Bachand tract value would increase to 72.5 percent stocked.

Table 5.—*Seedling stocking*

Location	Percentage of stocked[1] 3-foot furrow segments
Rosen woodland	87.8
Ross brushy hillside	83.8
Ross brushland	83.8
Smith woodland	73.8
Smith wooded hillside	70.0
Smith field	65.0
Nalf woodland	62.5
Brandt field	61.5
Bachand woodland	45.0

[1] Duncan's new multiple-range test. Means not connected by a vertical line differ significantly at the 5-percent level.

Efficiency of the Furrow-Seeder

A combined measure of the efficiency of the furrow-seeder method is possible by testing statistically the machine time per hundred stocked 3-foot furrow segments. The effect of location was again significant at the 1-percent level (table 6).

This measure of production efficiency indicates that a large difference exists in time expended per unit of stocked furrow. The time-stocking ratio was nearly five times greater on the Bachand tract than on the Brandt field. The four top-ranked locations had dominant vegetation that offered relatively little resistance to the furrow-seeder equipment and little or no stone. The second group of four locations showed the effects of increasing amounts of stone and a heavier stand of dominant trees.

It would appear then, that the best economic choice might be to seed those locations that offer the least resistance to machine

Table 6.—*Furrow-seeder time per 100 stocked 3-foot segments, in minutes*

Location	Time/100 stocked[1] 3-foot segments
Brandt field	14.54
Ross brushland	18.92
Rosen woodland	20.81
Ross brushy hillside	21.22
Smith wooded hillside	32.44
Smith field	34.28
Smith woodland	36.73
Nalf woodland	43.66
Bachand woodland	69.64

[1] Duncan's new multiple-range test. Means not connected by a vertical line differ significantly at the 5-percent level.

Table 7.—*Estimated furrow-seeding costs*

Item	Cost
Crawler tractor (40 hp.) equipped with dozer blade and double hydraulic system, plus operator. (Contract rate: Includes depreciation, maintenance, repairs, profit)	$ 9.50/hr.
Depreciation, maintenance, and repairs on fireline plow and seeder	$ 1.00/hr.
10-percent allowance to cover lost time for rest stops, moving equipment, and breakdowns	$ 1.05/hr.
TOTAL EQUIPMENT COST PER HOUR	$11.55/hr.
Job layout and technical supervision	$ 1.00/acre
Seed — 10,000 viable pine seeds per acre including protective coating and stratification	$ 3.50/acre
TOTAL SUPERVISION AND SEED COST PER ACRE	$ 4.50/acre

operations. However, this approach ignores site productivity, which over the course of a rotation will probably have a much greater effect on profitability of regenerating a given tract.

Cost of Furrow-Seeding

Cost figures that can be obtained from a study such as this are limited by the lack of more extensive practical trials and must be considered only rough estimates of actual operating expenses. However, even a tentative estimate of cost is helpful in evaluating the furrow-seeder method and providing a basis for comparison with other methods of regeneration.

Using our cost estimates (table 7) and the time to furrow-seed an acre (table 2), we calculated the cost of furrow-seeding on a per-acre basis at each of the nine locations (table 8).

We estimated that typical per acre cost will range between 7 and 15 dollars. These figures are much lower than those for planting nursery stock on similar sites in New England.

Table 8.—*Estimated per acre cost of furrow-seeding*

Location	Equipment-operator (cost/acre)	Supervision-seed (cost/acre)	Total (cost/acre)
Brandt field	$ 2.90	$4.50	$ 7.40
Ross brushland	5.40	4.50	9.90
Ross brushy hillside	6.20	4.50	10.70
Rosen woodland	6.30	4.50	10.80
Smith field	7.70	4.50	12.20
Smith wooded hillside	8.00	4.50	12.50
Nalf woodland	8.70	4.50	13.20
Smith woodland	9.30	4.50	13.80
Bachand woodland	10.70	4.50	15.20

CONCLUSION

A furrow-seeder for use under difficult Northeastern conditions has been successfully developed and tested. It performed efficiently over a wide range of soils, vegetation, and topography. From these trials, we estimate that direct seeding can be accomplished at about one-third the cost of planting nursery stock on similar sites. We believe this equipment will allow forest managers to economically establish pine on lands now occupied by brush or low-quality off-site hardwoods.

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Opportunities for PULPWOOD Growing Investment *in Southeastern Ohio*

by

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and

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Opportunities for PULPWOOD Growing Investment *in Southeastern Ohio*

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THE SITUATION

ECONOMICALLY, southeastern Ohio is characterized by low incomes and surplus labor (fig. 1). Because of the general low level of economic activity, this region has been included in the President's Appalachian anti-poverty program. Investment capital is in short supply so projects promoting rural area development are geared to take full advantage of natural land based resources to improve the local economy. The region is blessed with an extensive and highly productive timber resource. Small investments in this resource can provide timber producing income needed to expand economic growth.

Unfortunately, very few of the region's woodland owners are investing in timber production. They have indicated timber growing for "home use" and "profit" as primary reasons for holding woodland, yet they have been reluctant to adopt timber management practices which would conceivably contribute to the achievement of these objectives. They list more rewarding activities, too long a time to grow a crop, and lack of technical know-how as the primary obstacles to investment (*Mendel 1965*).[1]

Any successful effort to persuade these individuals to practice timber management must deal directly with these obstacles. Woodland owners must be shown that investment in timber production is feasible from the standpoint of available time and capital resources. More importantly they must be convinced that such an investment will pay dividends at least equal to alternative investment opportunities and that investment returns can be realized within a reasonable period of time.

Growing hardwood trees for pulpwood offers an opportunity to overcome the objections which woodland owners have to managing their timber. Pulpwood growing is a relatively short-term venture requiring minimum investments of time, capital, and

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[1] Names and dates in parentheses refer to literature cited, p. 22.

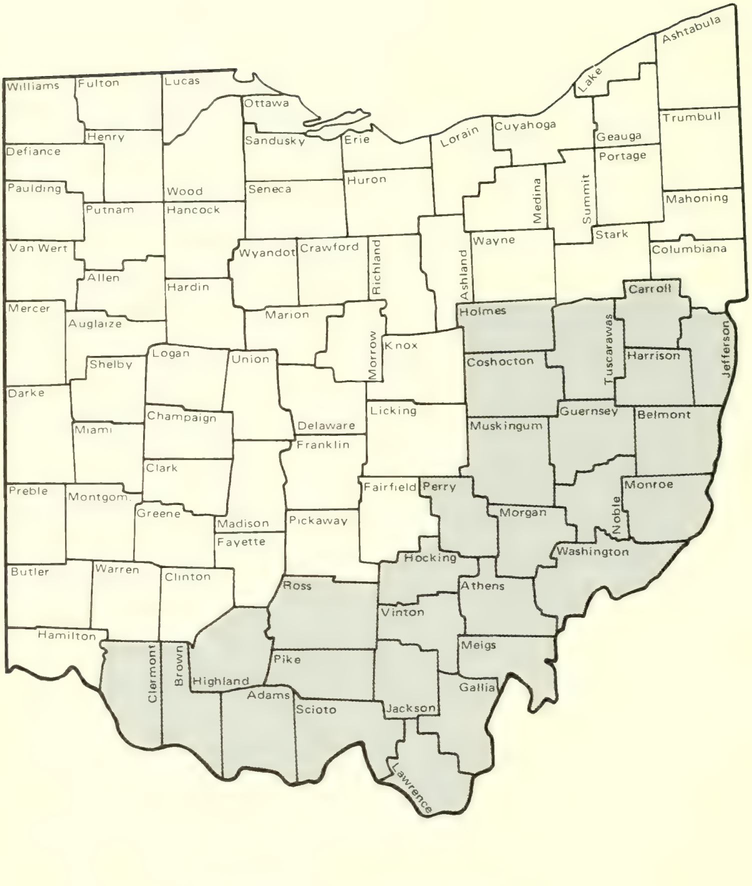

Figure 1. — The study area

technical know-how. Also, hardwood pulpwood is likely to have reliable local market outlets in southeastern Ohio for years to come. From 1960 to 1965 pulpwood production in the area has increased about 5 percent per year (*Kingsley and Dickson* 1967). The demand should continue to rise as pulpmills expand their productive capacities.

PURPOSE OF STUDY

The primary objective of this study is to evaluate management investment opportunities for growing pulpwood on various upland hardwood forest sites in southeastern Ohio.

With normal protection from fire, insects, disease, cattle and other destructive agents, hardwood timber, if left to grow, will develop into marketable pulpwood. However, forest management research has described an efficient system of management that will give greater pulpwood yields in a shorter period of time.

This investigation evaluates the economic desirability of employing this system.

The economic desirability of any timber producing project is measured by how much it adds to the value of a timber stand in relation to its cost and the length of time required to bring the stand to harvest. Annual compound interest rate of return is used as a means for gauging the economic desirability of the investment. Interest value measures the rate at which an investment grows toward the return it eventually generates.

Any pulpwood growing investment yielding a positive return is worthy of investment consideration. The incentive to invest will increase when the rate of return to pulpwood management approaches or exceeds the rate that can be earned in the owner's best financial alternative for capital investment.

DATA NECESSARY FOR INVESTMENT ANALYSIS

Three basic elements must be considered when evaluating the economic desirability of any investment in timber production:

(a) *Value* that the investment adds to a timber stand.

(b) *Cost* of the investment.

(c) *Time* required to realize a return on the investment.

Once this information is determined, the desirability of an investment in timber management can be measured and then compared with that of other investment opportunities.

Defining A System of Sound Silviculture

Timber management scientists have described a system of management designed to maximize timber yields by maintaining forest stands at the lowest level of stocking that will use all available growing space on a given forest site. The nature and timing of cultural treatments and timber harvests are described as part of the system.

Upland hardwoods are best suited to even-aged silviculture. They cannot be reproduced with good composition or growth in uneven-aged stands. After a stand of upland hardwood timber has been clearcut for industrial products (i.e., all trees down to 4 or 5 inches in diameter removed for sawlogs, pulpwood, charcoal wood, etc.), the general procedure for developing a new stand to maturity is *(U.S. Department of Agriculture 1962):*

(1) Make a *reproduction cutting* immediately after harvest. The purpose of this cutting is to provide the greatest number of desirable species and promote the most rapid growth of all species. Remove all residual trees more than two inches in diameter. If residual trees are left standing, their tops die back and the stems develop a mass of branches. Quality of these trees is low and they serve only to occupy space that would otherwise be filled with rapidly growing reproduction. Seed trees are not necessary for regeneration

—an adequate number of desirable seedlings will develop from seeds that have accumulated in the forest litter and from seedling sprouts of advanced reproduction.

(2) Approximately ten years after the reproduction cutting make a *pre-commercial thinning*. Select potential crop trees on a 15- to 20-foot spacing and release only those that need it. This spacing should provide acceptable stocking by the time the trees average 4 to 5 inches in diameter.

(3) As stands develop to merchantable size, make periodic *commercial thinnings* to keep crop trees growing rapidly. No thinning should reduce stand density below the point where the site can be fully utilized. Once a stand is in a condition to fully utilize the site, the timing and amount of thinning will depend primarily on productivity of the forest land. On better sites growth response after thinning will be greater, so thinning cycles will normally be shorter and thinning yields larger than on poorer sites.

(4) *Harvest* with a clear-cutting when the stand reaches maturity.

Reproduction cuttings and pre-commercial thinnings are management cost operations and represent the investment phase of the system. No marketable material would be harvested for sale from these cuttings. The calculation of returns on this investment is based on the difference between timber yields from managed stands and the yields that could be obtained from untreated stands grown over the same period of time.

For purpose of this study, managed stands are considered mature for pulpwood crops when the diameter of the trees in the stand average 10 inches d.b.h.[2]

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[2] Hardwoods 11.0 inches d.b.h. and larger are called sawtimber. Sound trees of this size usually have quality characteristics suitable for higher value products such as lumber logs, veneer logs and cooperage stock.

Determining Physical Timber Yields

At the Northeastern Forest Experiment Station, studies are underway to determine precise estimates of potential yields from managed hardwood stands on various upland forest sites. Results will be available in the future. In the meantime, data based on preliminary results of this research have been prepared and made available for use. These data are presented in Table 1.

Yield information is shown for site index[3] 40 through site index 80, the full range of commercial forest land productivity classes common to southeastern Ohio. Site 40 is rated the lowest class of land capable of producing commercial crops of timber, site 80 the highest.

Research completed by G. Luther Schnur provides estimates of timber volume expected to accumulate in untreated stands of even-aged upland hardwoods. Figure 2 presents this information in graphic form.

A casual comparison of the data shown in Table 1 and Figure 2 reveals that yields from managed stands are considerably greater than those from unmanaged stands grown over the same period of time. For example, Table 1 shows that a managed stand of hardwoods on site 60 will yield a cumulative volume of 38 cords of pulpwood in 48 years. Figure 2 indicates that without treatment the same stand can be expected to accumulate only 25 cords of marketable pulpwood volume during this same period of time. (See fig. 2—intersection of dotted line and site 60 yield curve.) It is this difference in yield that provides the basis for computing added value of investing in pulpwood management on site 60.

Estimating Treatment Costs and Yield Values

A meaningful calculation of economic desirability requires that physical estimates of input and return be transformed to

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[3] Site index—A classification of forest land in terms of inherent capacity to grow crops of industrial wood. Site index is expressed in terms of the height in feet that dominant trees, growing under natural conditions, will attain at age 50.

Table 1. — *Recommended cutting and estimated yields from well-stocked, even-aged stands of upland hardwood managed for pulpwood*

Kind of Cutting	Average Stand Diameter (inches)	Average Stand Age (years)	Average Volume Per Acre[1] Before this cut	This cut	After this cut (cords)	Cumulative cut
			ALL SITES			
Reproduction Cutting	0	0	0	0	0	0
Pre-commercial Thinning	1 to 3	10	0	0	0	0
	SITE CLASS 40 (10-year cutting cycle)					
Commercial Thinning	6	40	9	3	6	3
Commercial Thinning	8	50	17	4	13	7
Harvest Cut	10	60	23	23	0	30
	SITE CLASS 50 (9-year cutting cycle)					
Commercial Thinning	6	36	11	4	7	4
Commercial Thinning	8	45	19	5	14	9
Harvest Cut	10	54	26	26	0	35
	SITE CLASS 60 (8-year cutting cycle)					
Commercial Thinning	6	32	14	5	9	5
Commercial Thinning	8	40	22	6	16	11
Harvest cut	10	48	27	27	0	38
	SITE CLASS 70 (7-year cutting cycle)					
Commercial Thinning	6	28	18	6	12	6
Commercial Thinning	8	35	22	7	15	13
Harvest cut	10	42	28	28	0	41
	SITE CLASS 80 (6-year cutting cycle)					
Commercial Thinning	6	24	18	6	12	6
Commercial Thinning	8	30	24	7	17	13
Harvest cut	10	36	29	29	0	42

Source: Unpublished technical field guide prepared recently by Samuel F. Gingrich of the Northeastern Forest Experiment Station for Soil Conservation Service foresters.

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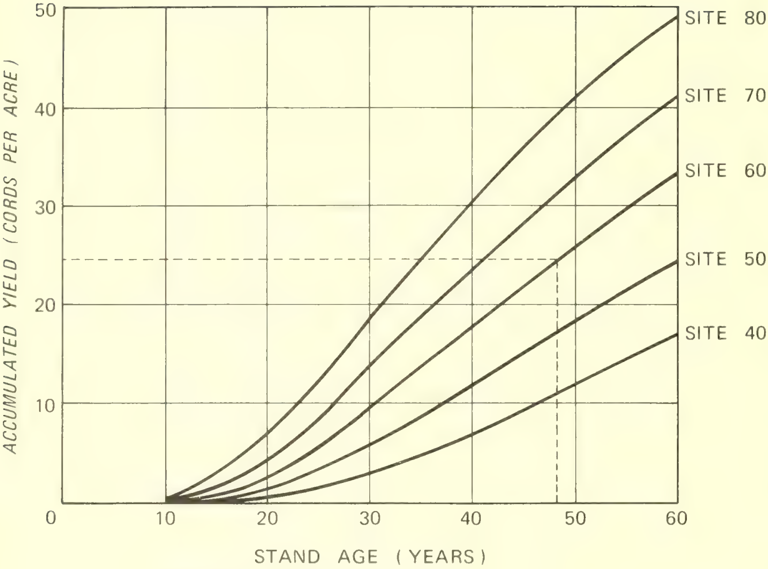
[1] Volume of merchantable wood to a 4" top.



SOURCE: G. LUTHER SCHNUR TABLE 5 1937.

Figure 2. — Accumulated yields in unmanaged, fully stocked, even-aged stands of upland hardwood

a common basis for comparison. In this study, investment costs and yield returns are expressed in units of dollars per acre.

The actual costs of reproduction cuttings and pre-commercial thinnings will depend on the amount of clean-up work needed to get the forest site into a desirable condition for new stand development and growth. Empirical data concerning these costs are not available for southeastern Ohio. So, three reasonable levels of variable costs were assumed and compared in making the investment analyses—cost options of $15 per acre, $10 per acre, and $5 per acre were used.

The value of added returns resulting from management was appraised in terms of stumpage income per acre. Reliable projections of future stumpage prices were not available; so prices based on current stumpage values in Ohio were developed. Current prices range from $1.50 to $3.00 per cord (*U.S. Dept. of Agric. 1965*). Assume that these prices increase at a compound interest rate of 1.5 percent per year. Then, 40 years hence (the approximate time required for site 80 stands to reach maturity) pulpwood stumpage would sell for an average price of about $4 per cord, and 60 years hence (the time required for site 40 stands to reach maturity) the price would average about $5 per cord.

For purposes of computing yield returns in this study, four alternative levels of stumpage prices were considered—$2, $3, $4, and $5 per cord. Prices were held constant for the investment period. In other words, if the price of pulpwood was set at $5 per cord, then all future yields were valued at $5 per cord.

A TECHNIQUE FOR MEASURING INVESTMENT POTENTIAL

As we stated earlier, the economic desirability of a timber management project is measured by how much the project adds to the value of a timber stand in relation to its cost and the length of time required to bring the stand to harvest. Compound interest values are used to measure the rate at which an investment grows toward the return it eventually generates. The amount and timing of both costs and returns are taken into account.

The general formula for computing the rate of return for a single investment (C) yielding a single added value (R_n) in n years is:

$$C\ (1 + i)^n = R_n$$

C, n and R are known; solve for i

The following is a hypothetical problem: if \$5.00 were invested at compound interest, what would the rate of interest have to be to realize an added value of \$75, 40 years hence. Substituting these values in the above equation:

$$\$5.00\ (1 + i)^{40} = \$75.00$$

And rearranging terms:

$$(1+i)^{40} = \frac{\$75.00}{\$\ 5.00} = \$15.00$$

Then by consulting the 40-year line in a $(1 + i)^n$ interest table:

$$i = 7.0 \text{ percent}$$

We are concerned with evaluating the desirability of projects having more than one cost and yielding more than one return during the investment period. The general formula for computing internal rate of return for any project having a series of annual investments generating a series of anual returns is *(Marty, et al 1966):*

$$C_1(1+i)^n + C_2(1+i)^{n-1} + C_3(1+i)^{n-2} \ldots + C_{n-1} + (1+i)^2 + C_n(1+i) = R_1(1+i)^{n-1} + R_2(1+i)^{n-2} \ldots + R_{n-1}(1+i) + R_n$$

It is assumed that all costs occurring during a given year are incurred at the beginning of the year and all returns occurring during a given year are assumed to have accrued at the end of the year.

But few timber management projects have costs and returns occurring every year. Such was the case with the management system employed in this study. It included two management costs and three yield returns occurring at different periods of time in the development of a stand. Also, five land productivity classes were considered. The formulas for computing rates of return for each of these five productivity classes were as follows:

Site 40: $C_R(1+i)^{60}+C_{PT}(1+i)^{50}=R_{CT_1}(1+i)^{20}+R_{CT_2}(1+i)^{10}+(RHC-RHC_N)$

Site 50: $C_R(1+i)^{54}+C_{PT}(1+i)^{44}=R_{CT_1}(1+i)^{18}+R_{CT_2}(1+i)^{9}+(RHC-RHC_N)$

Site 60: $C_R(1+i)^{48}+C_{PT}(1+i)^{38}=R_{CT_1}(1+i)^{16}+R_{CT_2}(1+i)^{8}+(RHC-RHC_N)$

Site 70: $C_R(1+i)^{42}+C_{PT}(1+i)^{32}=R_{CT_1}(1+i)^{14}+R_{CT_2}(1+i)^{7}+(RHC-RHC_N)$

Site 80: $C_R(1+i)^{36}+C_{PT}(1+i)^{26}=R_{CT_1}(1+i)^{12}+R_{CT_2}(1+i)^{6}+(RHC-RHC_N)$

Where:

C_R is the cost of reproduction cuttings

C_{PT} is the cost of pre-commercial thinnings

R_{CT_1} is the net return from the first commercial thinning

R_{CT_2} is the net return from the second commercial thinning

$(RHC\text{-}RHC_N)$ is the difference between returns from the final harvest of a managed stand and returns that would be forthcoming from harvesting an unmanaged stand grown over the same period of time

The exponents of the $(1 + i)$ terms indicate the number of years until final harvest.

Solving for "i" in each case requires a process of successive approximations in which various values for "i" are substituted in the above formulas until one is found that satisfies the equation. Consider, for example, the calculation of internal rate of return for a site 70 stand, assuming treatment costs of \$5 per acre and yields valued at \$4 per cord. A schedule of investment and return for this project can be tabulated as follows:

Investment	Return
1. \$5/acre reproduction cutting at age 0	1. First commercial thinning at age 28 6 cords/acre at \$4/cord=\$24
2. \$5/acre pre-commercial thinning at age 10	2. Second commercial thinning at age 35 7 cords/acre at \$4/cord=\$28
	3. Harvest cut at age 42 $(RHC - RHC_N) = \$4(28\text{-}26)$ $= \$8$

Again, the formula for computing internal rate of return for site 70 is:

$$C_R(1+i)^{42}+C_{PT}(1+i)^{32}= R_{\underset{1}{CT}}(1+i)^{14}+R_{\underset{2}{CT}}(1+i)^{7}+(RHC-RHC_N)$$

Substituting values from the above schedule gives:

$$\$5(1+i)^{42}+\$5(1+i)^{32}=\$24(1+i)^{14}+\$28(1+i)^{7}+\$8$$

The process of solving this equation can be started by using any interest rate. If seven percent is tried the equation becomes:

$$85.720 + 43.576 = 61.884 + 44.962 + 8.000$$
$$129.296 \neq 114.846$$

Since the cost side of the equation is greater than the return side, the interest rate of 7 percent must be too high. Trying 6 percent gives:

$$57.785 + 32.267 = 54.262 + 42.101 + 8.000$$
$$90.052 \neq 104.363$$

Now the cost side of the equation is less than the return side. Obviously, the 6 percent interest rate is too low. This process is continued until a balancing rate is found. In this case the rate was 6.5 percent.

Since five site productivity classes, three cost options, and four yield values were considered in this study, the economic desirability of 60 project opportunities representing a wide range of site, cost and return combinations could be measured and compared. Obviously, long-hand interest rate computations using a method of successive approximation would be costly and time consuming.

For that reason, this phase of the study was completed on electronic computers using a modified version of a computer program for interest rate computation developed by Row *(Row 1963).*

LIMITATIONS OF RETURN VALUES

Before analyzing study results, we should recognize two major limitations of using monetary rates of return to appraise the economic desirability of projects.

First, estimates of financial return to timber production may not always be the most important criterion for gauging the desirability of a timber management project. Forested lands yield a continuous flow of products and services other than timber. Included are such benefits as scenic value, water yield and conservation, and wildlife habitat which are often difficult to measure in dollar terms. The introduction of a system of timber management, such as that described in this study, will affect these other values. No attempt was made here to consider such effects.

Secondly, computed *absolute* values of financial return to timber production are based on assumed conditions of land productivity, timber yield, investment cost, stumpage price, and product marketability. Assumptions about present and future conditions may not be precise. And even if they are, it is not likely that the conditions described and evaluated to determine financial rates of return will apply to each and every situation encountered in the field.

Thus, it is not likely that an exact rate of return can be calculated for any given situation. We have examined a wide range of possible alternative conditions, thereby increasing the probability that the investment potential for any given situation can be approximated.

EVALUATION OF INVESTMENT OPPORTUNITIES

Rates of financial return for the 60 opportunity classes considered are presented in Table 2. On the better sites more pulpwood can be grown in a shorter period of time. Therefore, the site 80—$5 cost—$5 per cord income option produces the *highest* rate of financial return, 8.8 percent. Conversely, the site 40—$15 cost—$2 per cord income option produces the *lowest* rate of return and, in fact, the rate of return computed for this opportunity class is negative.

Thus, for all practical purposes, the rates of financial return computed for the 60 opportunity classes considered in this study range from a high of nearly 9 percent to a low of zero. The difference in absolute rate of return between one opportunity class and another is a result of disparate interactions of investment costs and yield returns over time.

We noted earlier the limitations to using absolute estimates of financial yield, such as those shown in Table 2, as direct measures of investment return. The *primary* value of these statistics is to provide a means for ranking the relative financial desirability of the several investment opportunity classes considered.

A glance at the absolute values of financial return shown in Table 2 reveals that some of the opportunity classes evaluated in this study are not worthy of consideration as investments. Pulpwood growing, even though short term relative to other forms of timber production, is still a 35 - 60 year venture involving risk and uncertainty, and woodland owners do have alternative investment opportunities.

Each woodland owner has in mind a level of return below which he would not consider an investment in forestry. This figure will vary from owner to owner. Nineteen of the 60 opportunity classes evaluated in this study produced absolute values of 4.0 percent return or greater. These are tabulated in Table 3 in descending order of their economic desirability as investments.

The values and rankings in Tables 2 and 3 give us a basis for discussing the relative influence of site productivity and levels of cost and return on investment potential.

Seven of the 19 opportunity classes listed in Table 3 occur on site 80 and six occur on site 70. Only three of the 24 opportunity classes evaluated for site 40 and 50 (Table 2) produce return values of 4 percent or greater. These occur only under projected conditions of low cost and high return.

Table 2. — *Rate of investment return from growing crops of hardwood pulpwood for stated levels of cost and income by site productivity classes*

Treatment cost level, per acre	Stumpage income level, per cord (Dollars)			
	2	3	4	5
Dollars	*Percent*	*Percent*	*Percent*	*Percent*
		SITE CLASS 40		
5	2.1	3.0	3.6	4.1
10	0.6	1.4	2.1	2.5
15	—	0.6	1.2	1.7
		SITE CLASS 50		
5	2.4	3.5	4.3	4.9
10	0.7	1.7	2.4	3.0
15	—	0.7	1.4	2.0
		SITE CLASS 60		
5	2.9	4.2	5.1	5.8
10	0.8	2.0	2.9	3.6
15	—	0.8	1.7	2.3
		SITE CLASS 70		
5	4.0	5.5	6.6	7.4
10	1.5	2.9	4.0	4.8
15	—	1.4	2.5	3.3
		SITE CLASS 80		
5	4.8	6.6	7.8	8.8
10	1.7	3.5	4.8	5.8
15	0.1	1.7	3.0	4.0

Table 3. — *Ranking of opportunity classes in descending order of their economic desirability as investments*[1]

Opportunity Class			Rate of Return
Site	Treatment Cost/Acre	Stumpage Return/Cord	
	Dollars	*Dollars*	*Percent*
80	5	5	8.8
80	5	4	7.8
70	5	5	7.4
80	5	3	6.6
70	5	4	6.6
80	10	5	5.8
60	5	5	5.8
70	5	3	5.5
60	5	4	5.1
50	5	5	4.9
80	10	4	4.8
80	5	2	4.8
70	10	5	4.8
50	5	4	4.3
60	5	3	4.2
40	5	5	4.1
80	15	5	4.0
70	5	2	4.0
70	10	4	4.0

[1] Investment alternatives producing a return of less than 4 percent are not listed.

Fourteen of the 19 top ranking opportunity classes include the treatment cost option of $5 per acre. When treatment costs range as high as $15 per acre, only one opportunity class produces a financial return value as great as 4 percent. That one occurs on the best site and only when the highest projected stumpage return value of $5 per cord is assumed.

When projected stumpage prices reach $5 per cord, eight of the opportunity classes evaluated in the study produce rate of return values of 4 percent and greater. If prices do not exceed the $2 per cord level, only two opportunity classes produce values as great as 4 percent and these occur on the better sites and under the low treatment cost assumption.

In general, it can be said that the most lucrative investment possibilities occur on sites 70 or better when treatment costs are less than $10 per acre and projected stumpage values exceed $3 per cord. If stumpage prices remain low over the investment period and treatment costs are high, none of the opportunity classes evaluated in this study appear favorable. In fact, when treatment costs are as high as $15 per acre and stumpage values

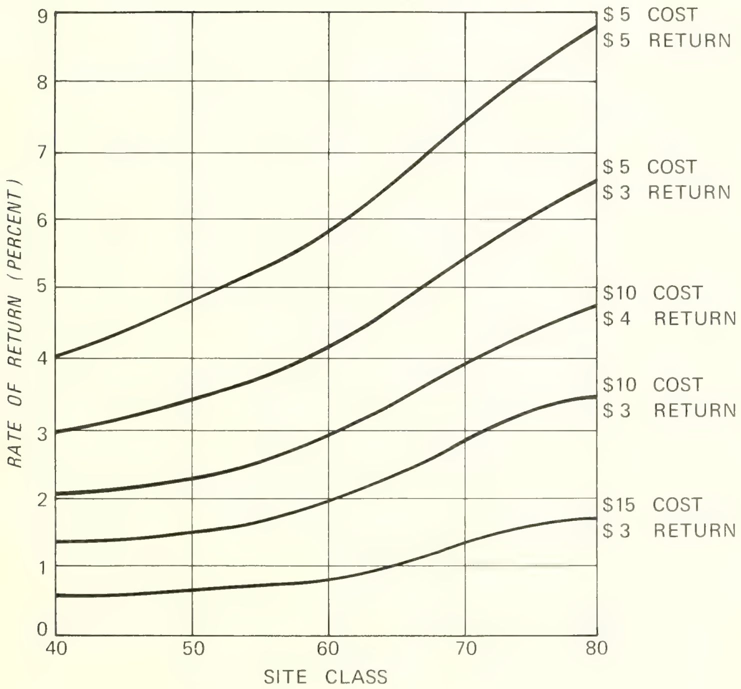


Figure 3. — Rate of return by site class for a range of assumed treatment cost-stumpage return conditions

are \$2 per cord, negative or zero returns result on all except the best site. Under these conditions, the woodland owner who wishes to grow pulpwood would be better off (from a financial standpoint) to let it grow in unmanaged stands.

Figure 3 illustrates the level of returns produced on various sites under five of the 12 possible cost-return combinations considered in this study. The set of cost-return conditions used in Figure 3 were selected to depict the range of relevant investment possibilities.

QUESTIONS IMPORTANT TO INVESTMENT DECISION MAKING

"How much can I afford to invest?" "What approximate rate of return can I expect to earn?" "What kind of price must I get to make the investment worthwhile?" Answers to these questions can be critical to the individual's investment decision making.

The set of formulas shown on page 11 of this paper can be utilized to produce approximate answers to these questions. Take for example the question, "How much can I afford to invest?"

Suppose that a woodland owner contemplates growing pulpwood on site 70 land under the system of management described in this study. Let us further assume that he wants to earn at least a 4 percent compound rate of return on his investment and that he expects stumpage prices to average about \$4 per cord over the investment period (42 years for site 70). An approximation of the maximum amounts he can invest in reproduction cuttings and precommercial thinnings can be derived from the formula:

$$C_R(1+i)^{42} + C_{PT}(1+i)^{32} = R_{CT_1}(1+i)^{14} + R_{CT_2}(1+i)^{7} + (RHC - RHC_N)$$

Where:

$i = 0.04$

$R_{CT_1} = 6$ cords/acre @ \$4/cord = \$24

$R_{CT_2} = 7$ cords/acre @ \$4/cord = \$28

$RHC - RHC_N = \$4(28\text{-}26) = \$8$

Solving the equation for treatment costs gives a value of *$9.93* per acre.

Thus the maximum amount that can be invested in each of the practices of stand establishment and precommercial thinning, under the conditions described, is approximately $10 per acre.

Table 4. — *Optimum stand treatment costs per acre for stated levels of expected rate of return and estimated stumpage prices, by site productivity classes*

Estimated stumpage price per cord	Expected return (Percent)			
	2	4	6	8
Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*
SITE CLASS 40				
2	5.13	2.10	0.89	0.39
3	7.70	3.15	1.33	0.58
4	10.27	4.20	1.77	0.77
5	12.84	5.25	2.22	0.97
SITE CLASS 50				
2	5.92	2.76	1.32	0.64
3	8.87	4.14	1.98	0.96
4	11.83	5.52	2.63	1.28
5	14.79	6.90	3.29	1.61
SITE CLASS 60				
2	6.75	3.56	1.90	1.03
3	10.12	5.33	2.85	1.54
4	13.50	7.11	3.80	2.06
5	16.87	8.89	4.75	2.57
SITE CLASS 70				
2	8.59	4.97	2.90	1.71
3	12.88	7.45	4.35	2.56
4	17.18	9.93	5.79	3.41
5	21.47	12.41	7.24	4.26
SITE CLASS 80				
2	9.42	5.95	3.78	2.42
3	14.13	8.93	5.67	3.62
4	18.84	11.90	7.56	4.83
5	23.55	14.88	9.45	6.04

The same technique can be used to answer questions concerning any of the variables contained in the investment equations, i.e., stumpage prices, investment rates of return and treatment costs. The estimator needs only to approximate reasonable values for all variables except one and then solve for that unknown.

Table 2 can be used as a guide for answering the questions, "What approximate rate of return can I expect to earn?" Assume that a woodland owner is thinking about installing the system of management described in this study on site 60 and he expects treatment costs to average $10 per acre and stumpage prices to average $4 per cord. A look at Table 2 indicates he might

Table 5. — *Minimum stumpage prices per cord for stated levels of expected rate of return and treatment costs, by site productivity classes*

Estimated treatment cost per acre	Expected return (Percent)			
	2	4	6	8
Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*
		SITE CLASS 40		
5	1.95	4.77	11.28	29.03
10	3.90	9.53	22.56	58.06
15	5.84	14.30	33.84	87.09
		SITE CLASS 50		
5	1.76	3.62	7.59	15.57
10	3.53	7.25	15.19	31.14
15	5.29	10.87	22.78	46.72
		SITE CLASS 60		
5	1.48	2.81	5.26	9.73
10	2.96	5.62	10.53	19.46
15	4.44	8.44	15.79	29.19
		SITE CLASS 70		
5	1.17	2.01	3.46	5.86
10	2.33	4.03	6.93	11.73
15	3.50	6.04	10.39	17.59
		SITE CLASS 80		
5	1.06	1.68	2.64	4.14
10	2.12	3.36	5.29	8.28
15	3.18	5.04	7.93	12.42

expect a rate of return on his investment of approximately 3 percent.

Tables 4 and 5 have been prepared as guides for answering respectively, the questions, "How much can I afford to invest?" and "What kind of price must I get to make the investment worthwhile?"

CONCLUSION

This paper has evaluated opportunities for investing in a system of hardwood pulpwood production in southeastern Ohio. Estimates of financial rate of return were calculated for 60 options encompassing a wide range of possible investment alternatives.

Absolute values of financial return ranged from negative to 8.8 percent. The best investment possibilities occur on site index 70 or better land when treatment costs are less than $10 per acre and projected stumpage prices exceed $3 per cord.

Results of this study can be logically applied to other areas in the Central Hardwoods Region where conditions of timber productivity, woodland owner attitudes toward timber growing, and pulpwood market availability are similar.

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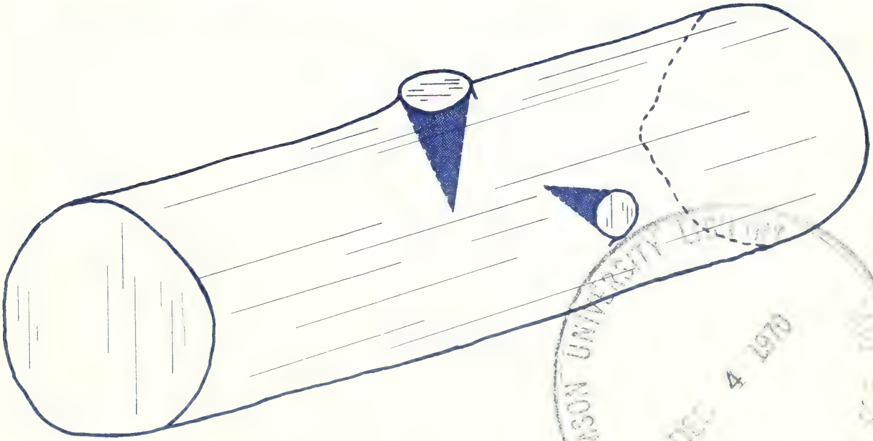
SAWMILL SIMULATION:

data instructions and computer programs



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HUGH W. REYNOLDS was graduated from the University of Minnesota in 1950 with a B.S. degree in electrical engineering. His engineering experience consists of work in mining, heavy equipment manufacturing, and design of specialized research equipment. He did research work in drying of softwoods for private industry on the West Coast, and for the last 3 years he has been working at the Forest Products Marketing Laboratory in the utilization of low-grade hardwoods.

SAWMILL SIMULATION:

data instructions and computer programs

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TO SAW ONE LOG IN DIFFERENT WAYS

BY USING A COMPUTER to simulate the sawing, we have devised a way to saw the same log in many different ways to find out which way gets the best yield from the log.

Sawmill production managers often find it hard to tell what sawing pattern will yield the most. If sample logs are sawed in one sawing pattern, they cannot be reassembled and sawed again in a different pattern. And if a new sample of logs is used for each new sawing pattern, it is hard to tell if differences in yield are due to the sawing patterns or are due to natural differences between the logs in the samples. But by using a computer to simulate the sawing, the same log sample can be sawed again and again, and yields of the different sawing patterns can be compared.

This paper has been prepared for use by sawmill production managers and researchers who want to use this simulated sawing technique. It is assumed that they can obtain the help of a competent computer programmer. All details needed by the computer programmer to use this computer program are given in this paper. Terms are used as defined in Sippl's *Computer Dictionary and Handbook*.[1]

Briefly, this technique of sawmill simulation, using a computer program called DEFECT is as follows:[2]

---

[1] Sippl, Charles J. COMPUTER DICTIONARY AND HANDBOOK. 766 pp. Howard W. Sams and Co., Inc., and Bobbs-Merrill Co., New York, N. Y., 1967.

[2] This technique was described in general terms in a companion paper: Reynolds, Hugh W., and Charles J. Gatchell. SAWMILL SIMULATION: CONCEPTS AND COMPUTER USE. USDA Forest Serv. Res. Note NE-100, 5 pp., illus. NE. Forest Exp. Sta., Upper Darby, Pa. 1969.

- A representative sample of logs is selected and sawed into boards.
- Each board is identified, and the defects in each board are identified by class, size, and location. This information is encoded into the computer.
- The computer, in effect, reassembles the boards into their respective logs, and records the locations of all defects in the logs.
- The computer is instructed on what sawing patterns are to be used.
- Computer program DEFECT simulates the sawing and shows how the defects appear in each new board for each new sawing pattern.

The results of simulated sawing from program DEFECT are in a form that can be used directly with another computer program called YIELD.[3] Program YIELD was developed by the USDA Forest Service to simulate the ripping and trimming of boards. Thus, by using these two computer techniques, the effects of different sawing and ripping and trimming patterns on mill yield of boards, and on the yield of cuttings from these boards, can be studied.

MAKING THE LOG MODEL

The log model is constructed from a sample of real logs to insure that the model represents the real situation. The sample of logs must be chosen carefully by regular sampling techniques to fit the design of the experiment that the scientist is making. Only one sample is required because it will be used repeatedly for each sawing technique and product specification being studied in the experiment.

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[3] Wodzinski, Claudia, and Eldona Hahm. A COMPUTER PROGRAM TO DETERMINE THE YIELD OF LUMBER. 33 pp., illus. USDA Forest Serv. Forest Prod. Lab., Madison, Wis., 1966.

The internal defects of each sample log must be coded and located in a three-dimensional grid. Length dimensions are located by X-coordinates; width dimensions are located by Y-coordinates; and thickness dimensions are located by Z-coordinates. In the program as listed,[4] the X, Y, and Z axes are each divided into $1/4$-inch units.

By using the three-dimensional grid, any point on the surface or in the interior of the log can be represented by naming the X, Y, and Z coordinates of that point. Because this makes it possible to "see" the internal defects in the bolt or log, the model is called a "glass log" model. The illustrative examples in this report are taken from the simplified glass log shown in figure 1.

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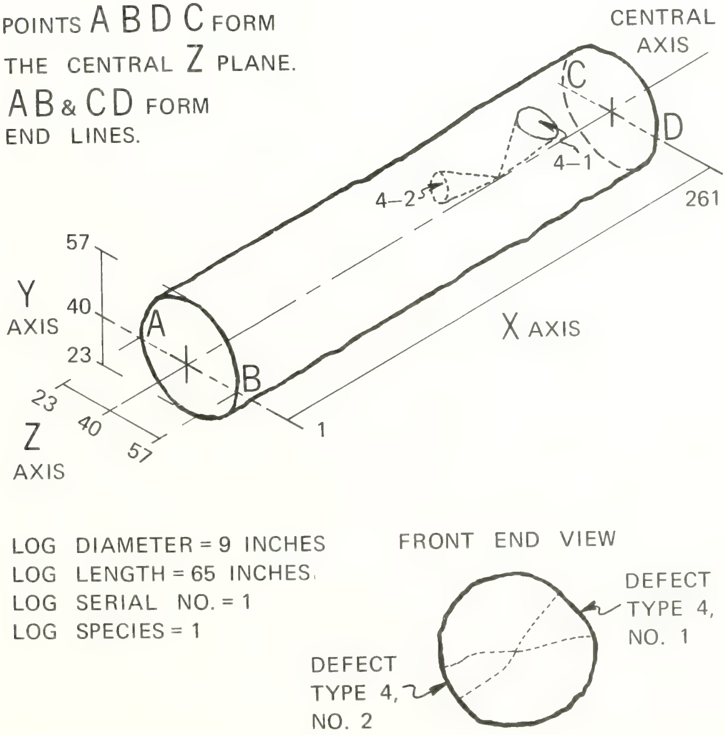
[4] This refers to the program DEFECT listings appearing in the appendix of this report.

Figure 1.—The glass log.



1.1 Central Axis

The central axis of each log is located by marking the center of both ends of the log. An imaginary line through these two points forms the log's central axis. In the program as listed, the coordinates of the central axis are always Y 40 and Z 40, the center of the Y-Z grid.

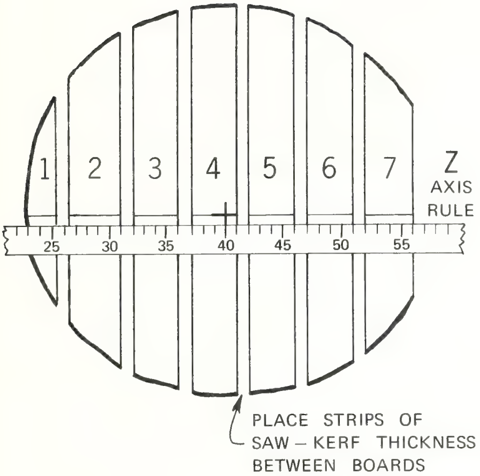
The four grading faces of the log are then selected. If the glass log model is to be used to determine yields of graded cuttings, the external log defects should be located at the edges of the faces. If structural lumber is to be sawed from the glass log model, the external log defects should be located in the center of the faces. A straight line is then drawn on the diameter across the end of the log from the middle of one face to the middle of the opposite face. This end line is drawn on the other end of the log, using the same two faces. The plane connecting these two lines is the central Z plane.

1.2 Sawing the Logs

Boards are sawed from the log parallel to the central axis and at right angles to the central Z plane. The generated board surfaces are Y planes. The log is placed on the saw carriage with the end lines horizontal and with the central axis of the log parallel to the saw line. Boards are then sawed through and through without turning the log, and without making any adjustments for log taper. Each board is numbered consecutively as it is sawed. Boards of any thickness may be sawed, and saw kerf of any width may be used.

1.3 Locating the Board Surfaces

After the sample logs are sawed, they must be reassembled into their original form so that the surfaces of the board can be located accurately (fig. 2). A simple aid to positioning is the insertion of thin strips (thickness equal to the saw kerf) between adjacent boards. The consecutive numbering of the boards gives the position of each board within the log. Care must be taken to line up the end-line marks. When the log is tightly banded, each



Z PLANE NUMBERS FOR BOARDS

BOARD	Z PLANE
1	25
2	26 & 31
3	32 & 36
4	37 & 41
5	42 & 46
6	47 & 51
7	52 & 56

Figure 2.—Board-surface identification.

board will be in the exact position it was in before the log was sawed.

A rule must be made that duplicates the Z-axis increment scale. The rule is held against the end of the log, parallel to the end line, with the center of the rule in line with the center of the log end. The Z-axis coordinate of each surface of each board is read from the rule.

1.4 Marking the Boards

The outside of the log is located in the three-axis system by noting the surface of each board (Z axis), the width of each board (Y axes), and the length of each board (X axes). Each defect is located in the three-axis system by noting the surface of the board on which the defect occurs (Z axis), the width of a rectangle enclosing the defect (Y axes), and the length of this rectangle (X axes).

The first step in this procedure is to mark the boards. Lay the boards face up across a table, in sequence. For the log shown in figure 2, the sequence would be as follows. Board 1 will be at the left end of the table, with Z-plane 25 up and with the top edge of the board at the left end of the table. Board 2 will be next, with Z-plane-31 surface up and with the top edge of board 2 next to the bottom edge of board 1. This method is followed until the bottom edge of board 7, Z-plane-56 surface up, is at the right end of the table.

Now the defects are marked by the type of defect, and a number is assigned to the defect. Since one defect may appear on more than one board surface, the defect-type/defect-number system is used to follow the defect through the log.

In the program as listed, defect types 1 to 4 refer to the defects allowed in various hardwood cuttings. Defect type 5 indicates the board outline.

Each defect on each board should be marked around its periphery, using a lumber-marking crayon. This is done only on the top side of the board, because program 3333 interpolates between the top faces of two adjacent boards to find the location of defects on the back side of the first board. The defect type number should be written beside each defect.

By giving identification numbers to the defects, different defects of the same type can be correctly interpolated. Identification numbers can be used in any order as long as integer values are used. Numbers must be not smaller than 1 nor larger than 999. In the computer program, interpolation is completed for one log at a time, so repeating the same identification numbers on different logs is allowable.

When a defect ends within a board, a straight line should be drawn on the next board in the position that the defect would have occupied if the defect had continued. This line must be given the type number and identification number of the defect. When a defect starts within a board, the line is drawn on the face of the board.

1.5 Encoding the Board Data

The outside of the log is located by encoding the width and length of each board. Encoding is done by placing each board on a special table. This table has a raised molding on all four sides.

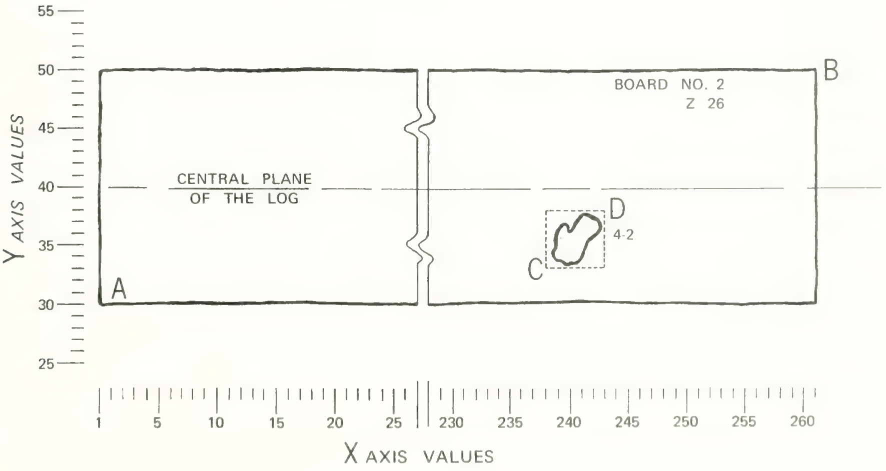
The two end moldings are marked with the Y-axis values. For the program as listed, this marking would be in 1/4-inch units numbered 1 to 80. Number 40 would be at the center of the table. The two edge moldings are marked with the X-axis values. For the program as listed, this marking would be in 1/4-inch units. Number 1 would be at the left end of the table.

The board is positioned on the table so that the line formed by the central plane of the log lies on the Y-40 axis, and the left end of the board is in line with X1.

In the program as listed, each board is considered a rectangle, and each log is considered a right cylinder. The lower left corner of a board, point A in figure 3, and the upper right corner of a board, point B in figure 3, are located by measuring from the side moldings.

When waney-edged boards are to be considered, additional encoding steps must be taken. First, the rectangle enclosing the

Figure 3.—Encoding the board data.



POINT A – BOARD OUTLINE LOWER LEFT CORNER – Y AXIS 30 – X AXIS 1
POINT B – BOARD OUTLINE UPPER RIGHT CORNER – Y AXIS 50 – X AXIS 261
POINT C – DEFECT OUTLINE LOWER LEFT CORNER – Y AXIS 33 – X AXIS 238
POINT D – DEFECT OUTLINE UPPER RIGHT CORNER – Y AXIS 38 – X AXIS 243

board is chosen (see section 2.1 of the sawing instructions). Second, the lower left and upper right corners of this rectangle are encoded as the board outline. Third, the areas between the rectangular outline and the actual board edges are treated as defects. A new defect type number must be assigned to these void areas and the board outline defect type number must be increased by one, because the programs always assume that the largest defect type number encountered refers to the board outline.

Each defect is located by encoding a rectangle enclosing the defect. These rectangles have their lower left and upper right corners encoded to the nearest increment as measured from the side moldings on the table. Figure 3 illustrates the procedure for defect type 4, number 2.

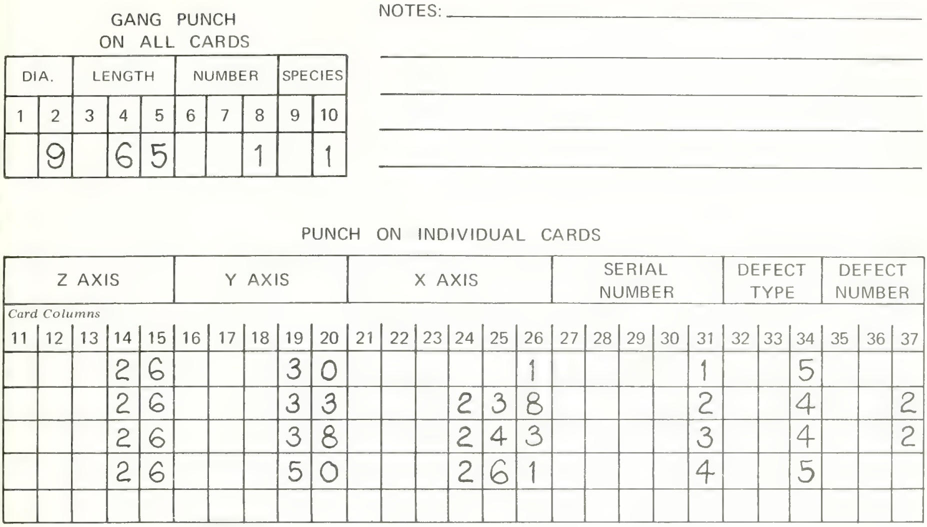
The straight lines used to indicate the start or end of a defect are encoded by recording the coordinates of the left end of the line and the right end of the line. In this case the Y-axis values are the same for both ends of the line.

1.6 Data Conversion to System/360

The log-model data must be keypunched into cards and then converted onto magnetic tape. Figure 4 shows the form on which the data are recorded. The 80-column card format is as follows:

Item	*Field*	*Columns*
Log diameter in inches	I2	1-2
Log length in inches	I3	3-5
Log serial number	I3	6-8
Log species code number	I2	9-10
Board Z axis	I5	11-15
Board or defect Y axis (lower left or upper right corner of rectangle)	I5	16-20
Board or defect X axis (lower left or upper right corner of rectangle)	I6	21-26
Card serial number	I5	27-31
Defect type number	I3	32-34
Defect serial number	I3	35-37

The first four fields, columns 1 to 10, are gang-punched since they will remain constant for each log. The other fields are punched individually. Each line of data from the board data sheet is placed



GANG PUNCH
ON ALL CARDS

DIA.		LENGTH			NUMBER			SPECIES	
1	2	3	4	5	6	7	8	9	10
	9		6	5			1		1

NOTES:

PUNCH ON INDIVIDUAL CARDS

Card Columns

Z AXIS					Y AXIS					X AXIS						SERIAL NUMBER					DEFECT TYPE			DEFECT NUMBER		
11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
			2	6				3	0						1					1			5			
			2	6				3	3				2	3	8					2			4			2
			2	6				3	8				2	4	3					3			4			2
			2	6				5	0				2	6	1					4			5			

Figure 4.—Example of a board data sheet.

on a separate card. The card serial number is for convenience in keypunching and verifying.

Keypunching the cards from the board data sheets must be done without error. Since each card describes only one corner of a rectangle, there must be two paired cards for each rectangle. Warning! If one card of a pair is missing, the computer program will read the next card in the file as the pair card.

The program listed reads the input data from a magnetic tape reel, so card-to-tape conversion is required. The 9-channel magnetic tape is coded in the IBM system/360 EBCD code. The data tape is labeled A333310 in the Washington Data Processing Center (WDPC)[5] library as shown in figure 5, tape reel 1.

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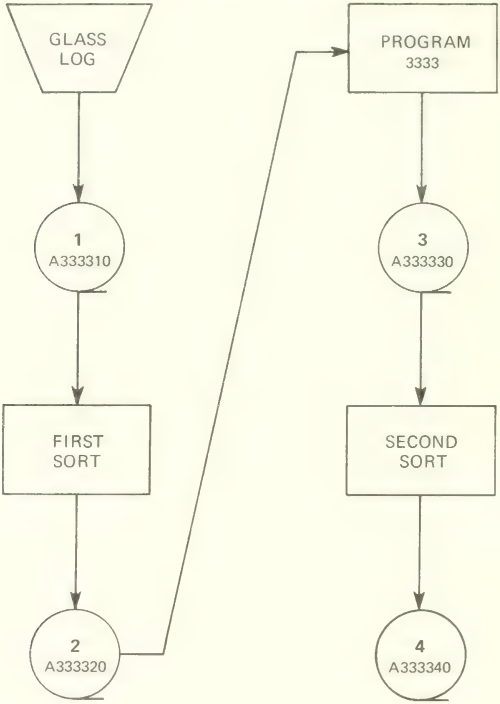
[5] Washington Data Processing Center, Statistical Reporting Service, U. S. Department of Agriculture, Washington, D. C.

Figure 5.—Interpolation-program logic steps.



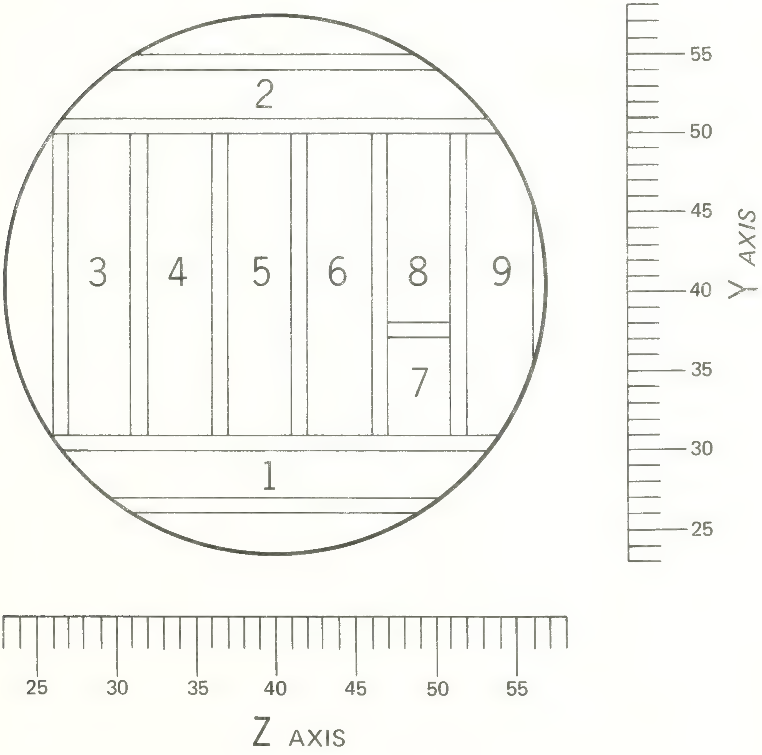
WRITING THE SAWING INSTRUCTIONS

A set of specific sawing instructions must be written for each sawing technique and for each log diameter. First, a sawing diagram is made for each combination of log diameter and sawing technique. The sawing instructions are then written from these diagrams. Keypunching and conversion to magnetic tape put the sawing instructions into the form required by the system/360 computer.

2.1 Sawing Diagram

One full-scale sawing diagram is made for each sawing method in each log diameter (fig. 6). The diagram represents the end of the log or, in the case of distorted logs, the end of a cylinder enclosing the log with the center of the diagram at the center of the log. The boards to be sawed are drawn to scale on the diagram. Any combination of board width, thickness, and saw kerf may be used. The program as listed is limited to sawing boards horizontally or vertically.

Figure 6.—Sawing diagram and sawing instructions.



SAWING INSTRUCTIONS

Board	Control	Surface	Left Edge	Right Edge
1	1	Y27	Z30	Z50
2	1	Y54	Z30	Z50
3	2	Z27	Y31	Y50
4	2	Z32	Y31	Y50
5	2	Z37	Y31	Y50
6	2	Z42	Y31	Y50
7	2	Z47	Y31	Y38
8	2	Z47	Y38	Y50
9	2	Z56	Y34	Y47

2.2 Sawing Instructions

Each sawing diagram is used to write one set of sawing instructions. The surfaces of horizontal boards are indicated by the Y axis nearest the surface. The surface of the vertical boards are indicated by the Z axis nearest the surface. The board edges are indicated by the nearest Z axes for horizontal boards and by the nearest Y axes for vertical boards. All boards are sawed the full length of the log. The Z- and Y-axis values, together with identification and control information, are written on the data sheet (fig. 7).

Each set of sawing instructions is identified by four items: log diameter, board thickness, kerf thickness, and sawing method number. The log diameter is taken from the sawing diagram diameter and is used to match the sawing instructions to the correct size of log. The log diameter is given in 1-inch intervals. The board and kerf thickness are used as notes only and are not used in the computing.

The sawing method (technique) number separates different sawing instructions for each log diameter. Any numbering system with numbers ranging from 1 through 99 may be used. The board

Figure 7.—Sample data sheet for sawing-method instructions.

LOG DIAMETER (INCHES)		BOARD THICKNESS (IN 1/32 INCH)				KERF THICKNESS (IN 1/32 INCH)			SAWING METHOD		PLANE CONTROL		BOARD SURFACE			LOWER OR LEFT EDGE			UPPER OR RIGHT EDGE			OUTPUT CONTROL		BOARD NUMBER		
Card Columns																										
1	2	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	34	35	36	37	38
	9			3	1			4		2		1		2	7		3	0		5	0		4			1
	9			3	1			4		2		1		5	4		3	0		5	0		4			2
	9			3	1			4		2		2		2	7		3	1		5	0		4			3
	9			3	1			4		2		2		3	2		3	1		5	0		4			4
	9			3	1			4		2		2		3	7		3	1		5	0		4			5
	9			3	1			4		2		2		4	2		3	1		5	0		4			6
	9			3	1			4		2		2		4	7		3	1		3	8		4			7
	9			3	1			4		2		2		4	7		3	8		5	0		4			8
	9			3	1			4		2		2		5	6		3	4		4	7		4			9

number is taken from the sawing diagram. Any numbering system may be used, and board numbers can range from 1 through 999.

Two types of output-control statements are made: the plane control and the output control. The plane control is used to separate the sawing instructions for horizontal boards (plane control 1) from the sawing instructions for vertical boards (plane control 2). All statements must contain either plane control 1 or plane control 2. This is done to reduce the computing time in the IBM system/360.

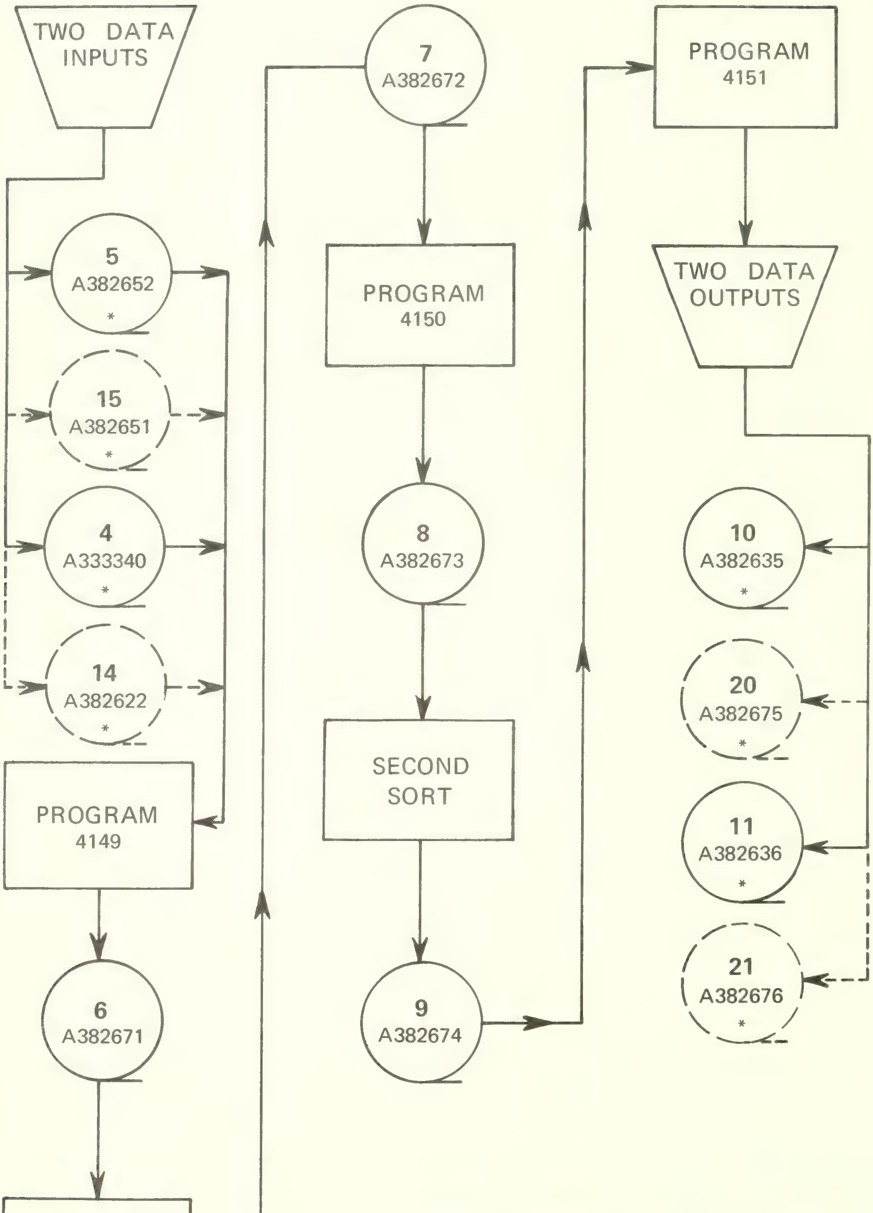
The output control (product specification) specifies the types of defects to be considered in each board. In the program as listed, defects of types 1 through 4 are recognized. Output control 4 limits the defects to be recognized to type 4 only. Output control 3 includes defect types 3 + 4. Similarly, output control 2 recognizes defect types 2 + 3 + 4; and output control 1 recognizes all defects (types 1 + 2 + 3 + 4) in the boards. This method is used because program YIELD cannot differentiate between grades of defects. In effect, program DEFECT removes specific grades of defects from consideration. The defects remaining in the boards after program DEFECT is completed are considered unusable areas by program YIELD. Program YIELD cuts around these unusable areas to make cuttings from the boards.

2.3 Data Conversion to System/360

The sets of sawing instructions must be keypunched into cards and then converted onto magnetic tape. Figure 7 shows the form on which the sawing instructions are written. The format is:

Item	*Field*	*Columns*
Log diameter in inches	I2	1-2
Board thickness in 1/32-inch increments	14	5-8
Kerf thickness in 1/32-inch increments	13	9-11
Sawing method	I2	12-13
Plane control	I2	14-15
Board surface to nearest increment	I3	16-18
Board edge to nearest increment		
lower or left edge	I3	19-21
upper or right edge	I3	22-24
Output control	I2	34-35
Board number	I3	36-38

Figure 8.—Sawing-program logic steps.



*FOR VERTICAL SAWING REELS 4 & 5-10 & 11 ARE USED.
FOR HORIZONTAL SAWING REELS 14 & 15-20 & 21 ARE USED.

The entire group of sawing instruction sets must be punched on 80-column cards. These cards must then be sorted and read onto two 9-channel magnetic tapes with the EBCD code used with the IBM system/360.

First, the cards with horizontal board-sawing instructions (plane control 1) are separated from the vertical board-sawing instructions (plane control 2). Each of these card decks is then sorted in major to minor sorts, with increasing values as follows: log diameter, sawing method, and board surface. The other fields are not used for sorting. The sorted horizontal board deck is read onto tape 15 (A382651) (fig. 8). The sorted vertical board deck is read onto tape 5 (A382652).

COMPUTER PROGRAM DEFECT

Program DEFECT consists of four sets of programs and sorting routines that are run separately. The data from the log model (**1.6**) are fed into the interpolation program. The interpolated log model data and the vertical-sawing instructions are fed into the vertical-sawing program. The interpolated log model and additional instructions are used for the vertical-data-conversion program. The converted log model (**5.0**) and the horizontal sawing instructions are fed into the horizontal-sawing program. All four of these program sets are listed in the appendix. The sorting routines are not listed, but the sort sequences are given so that the sorting routines can be written easily, using the sort/merge routine[6] for the system/360.

3.0 Interpolation

Interpolation is the set of programs and sorting routines that is used to establish the defect locations and board outlines on all the vertical axes. The log model contains defect data and board outlines for one surface of each board sawed from the logs. By interpolation, the defect data and the board-outline coordinates are found for all the other Z axes. In this way, simulated sawing can be done on any axis. All the interpolation for all the logs in the glass log model are done at one time (a single job) under the control of the Job Control Language (JCL) for the system/360 computer.

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[6] Anonymous. IBM system/360, operating system, sort/merge, program number 360S-SM-023, file number S360-33, form C28-6543-3.

3.1 Input Requirements

The log model data (**1.6**) are used as the input data for interpolation. Only one input tape is required for the interpolation. This tape is shown in figure 5 as tape 1. This tape is catalogued at the WDPC as A333310.

3.2 First Sort

The log model data are sorted so that they are in the correct order for interpolation. Since the log model data may be accumulated in any sequence or order, the first step in the interpolation is to arrange the data by logical records (card images) so that the interpolation can be done correctly and efficiently. The major to minor sorts by increasing size of the field values are as follows: log diameter, log length, log serial number, log species, defect type, defect serial number, Z axis, Y axis, and X axis. The sorted data are fed onto scratch tape 2 (A333320) (fig. 5).

3.3 Program 3333

This program performs linear interpolation on the defect data and radial interpolation on board-outline data. After the first sort is completed, tape 2 (A333320) is used as input data to program 3333 without interruption of the job stream. In this program, the interpolation is accomplished by dividing the card images into two groups: defect types 1 to 4 for linear interpolation and defect type 5 for radial intepolation. (If linear interpolation were used for board edges, those boards near the sides of the log would be too narrow.)

3.3.1 Linear Interpolation

Linear interpolation is made between the first, third, fifth, etc., card images through each log. The first card image describes the lower left corner of a defect on a given Z plane.[7] The second card image describes the upper right corner of the same defect on the same Z plane. The third card image describes the lower left corner of the same defect as it appears on the next Z plane in the glass log (**1.2**).

The Y-axis values are interpolated for every Z-axis value between the Z-axis values on card images 1 and 3. The X-axis values from card images 1 and 3 are also interpolated this way. The interpolated data, in the form of new card images, are put onto scratch tape 3 (fig. 5). Then the first card image is dropped and the next card image on scratch tape 2 is read. Now the three-card image set is as follows: card image 1 describes the upper right corner of the defect on the first Z plane. Card image 2 describes the lower left corner of the same defect on the next Z plane found in the glass log. Remember that this was card image 3 in the first set of three card images. Card image 3 describes the upper right corner of the defect in the same Z plane as card image 2.

Now the interpolation for the upper right corner descriptions can be done as the lower left corners were done. By stepping along in this "drop a card image; pick up a card image" scheme, the defect is interpolated as it moves through the glass log.

When the defect serial number changes on a new card image being read from scratch tape 2, the end of the previous defect is recognized and the interpolation is terminated. Then a new set of three-card images is read and the interpolation process begins again. When the last type-4 defect is interpolated, this part of the program listed is finished.

3.3.2 Radical Interpolation

Radial interpolation is made between the first and third card images with defect type 5. The log is considered as a cylinder, or as a cylinder containing the distorted log, with radius RA2. The Y-axis values for card images 1 and 3 are used to find the heights of two right triangles with RA2 as the hypotenuse for both triangles. The Z-axis values are used to find the bases for these two right triangles. The Z axes between the Z axes in card images 1 and 3 are used to find additional bases for additional triangles. RA2 is the hypotenuse for these triangles; and the heights of these triangles are calculated. The heights are then used to calculate the Y-axis values.

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[7] When a Z or Y axis is used to describe a board surface, this Z or Y value locates a plane running through the log.

This system of radial interpolation can be used because the center of the log is always the same (the center of the Z-axis/Y-axis grid).

The X-axis values are linearly interpolated for the boards. The radially interpolated data are stored on scratch tape 3 (fig. 5). When the last defect type 5 card image is read for the first log, the next log is started on the linear interpolation program. When the last defect type 5 card image is read for the largest diameter log with the highest serial number, the interpolation is finished, scratch tape 2 has been read, and scratch tape 3 is completed.

3.4 Second Sort

After interpolation is completed, all the data are sorted to the format required for efficient simulated sawing. The card images are sorted in order of increasing size of the field values in the following major to minor sorts: log diameter, log length, log serial number, log species, Z axis, defect type, defect serial number, Y axis, and X axis. As the data are sorted for each log (second sort), the data are put onto tape 4 (fig. 5). Tape 4 is kept as a permanent tape, which is catalogued at the WDPC as A333340. Scratch tapes 2 and 3 are discarded, and tape 1 need not be kept unless corrections to the original glass log data are anticipated. The JCL control is ended when tape 4 is completed. The glass log data are now complete with the card images arranged in lower left and upper right corner pairs for each defect and board outline.

4.0 Vertical Sawing

Vertical sawing consists of finding the defects that fall within the vertical board outlines given by the sawing instructions. All vertical boards are sawed from all the glass log models by all sawing methods during one program run (one job). Figure 8 shows the process logic for this sawing.

Since program DEFECT was written to be used with program YIELD, the sawing output format for DEFECT is the same as the input format for YIELD.

4.1 Starting the Vertical Sawing

Two input tapes are used for the vertical sawing: interpolated log model (3.4) and the vertical sawing instructions (2.3).

4.2 Program 4149

Five operations are performed in this program: (1) the sawing instructions are matched to the correct logs by diameter, (2) all the defect data for the vertical boards are collected, (3) the defects whose type numbers are not involved in determining the quality of the end product (cuttings) are rejected, (4) small defects are rejected, and (5) the data are put into two new formats.

First, the correct sawing instructions are assigned to the log. This is done by matching the log-diameter field of the sawing instruction with the log-diameter field of the glass log. Second, each card image of the glass log data is examined to see if the Z axis on the card image is required by the sawing instructions. The card images with the correct Z axis are then examined to see if they are within the Y-axis edges of the board being sawed. If both qualifications are met, the card image is retained. Third, the width of the retained defect is examined to see if it is less than four increments. If it is less than four increments, the length of the defect is examined the same way. Defects less than four increments in length and width are too small and are not carried to tape 6 (fig. 8). Fourth, the sawing-instruction output control (2.2) is compared with the defect type on the retained card images. Unwanted defect types are not carried to tape 6. Fifth, the card images retained are put into two new card-image formats.

A header card is required for control in program YIELD. There is one header card for each board sawed. The card-image format, as it appears on tape 6 and subsequent tapes, is shown in table 1. This card image has 100 columns. The data in columns

Table 1.—Board header card format

Variable name	Column	Field
Log diameter	1-2	I2
Log length	3-5	I3
Log serial number	6-8	I3
Log species	9-10	I2
Board surface axis, Y or Z	12	H1
Board surface axis number	13-14	12
Sawing method	15-17	I3
Board thickness	18-20	I3
Saw kerf	21-23	I3
Output control	24-25	I2
Board number	34-35	I2
Number of defects	68-72	I4
Log diameter	81-82	I2
Log length	83-85	I3
Log serial number	86-88	I3
Log species	89-90	I2
Sawing method	91	I1
Plane control	92	I1
Board surface axis number	93-94	I2
Board number	95-96	I2
Card type[1]	97	I1
Defect type	98	I1
Defect serial number	99-100	I2

[1] Card type: 1=header, 2=board outline, 3=defect outline.

81 to 100 duplicate data found in columns 1 to 80 but are repeated so that sorting can be done efficiently One new field is added that shows the number of defects that have passed all of the program 4149 criteria. This field is used for control of program YIELD.

Program DEFECT uses two card images to describe each board outline or each defect. Program YIELD requires the same information on one card image format, as shown in table 2. As with the header card, columns 81 to 100 are used for sorting only.

The output from program 4149 is put into scratch tape 6 (fig. 8).

Table 2.—Board outline and defect card format

Variable name	Column	Field
Lower left corner: Y axis	1-3	I3
Lower left corner: X axis	4-7	I4
Upper right corner: Y axis	16-17	I2
Upper right corner: X axis	18-21	I4
Log diameter	22-24	I3
Log length	25-27	I3
Log serial number	28-30	I3
Log species	31-32	I2
Board surface axis number	33-36	I4
Board number	37-38	I2
Sawing method	39-41	I3
Board thickness	42-44	I3
Kerf thickness	45-47	I3
Defect type	48-50	I3
Defect serial number	51-53	I3

(Columns 81-100 are the same as table 1)

4.3 First Sort

The data are sorted so that the board data appear in the proper header, outline, and defect card image sequence. The header card must be first, followed by the card giving the board outline, and concluding with all of the defect cards making up the rest of the board deck. The first sort arranges the card images in this fashion and also sets the card images to appear with the small-diameter short logs first. The major to minor sort fields in increasing value are: log diameter, log length, log serial number, log species, sawing method, plane control, surface axis, board number, card type, defect type, and defect serial number.

4.4 Program 4150

Three operations are performed in this program: (1) the straight interpolation lines (1.4) are eliminated from the output, (2) the small defects are again checked for size and eliminated if required, and (3) the number of defects are recounted in each board and the header card is corrected when required.

Figure 9.—Example of output from program DEFECT.

ONE-INCH-THICK VERTICALLY SAWED BOARDS, LISTING FROM TAPE 10 (A382635, figure 8)

```
9 65  1 1 Z27  2 31  4 4        3                             1       9 65  1 12227 315 0
31   1         50 261  9 65  1 1  27 3  2 31  4  5  0                  9 65  1 12227 325 0
33 238         38 243  9 65  1 1  27 3  2 31  4  4  2                  9 65  1 12227 334 2
9 65  1 1 Z32  2 31  4 4        4                             1       9 65  1 12232 415 0
31   1         50 261  9 65  1 1  32 4  2 31  4  5  0                  9 65  1 12232 425 0
34 236         39 242  9 65  1 1  32 4  2 31  4  4  2                  9 65  1 12232 434 2
9 65  1 1 Z37  2 31  4 4        5                             1       9 65  1 12237 515 0
31   1         50 261  9 65  1 1  37 5  2 31  4  5  0                  9 65  1 12237 525 0
36 235         40 242  9 65  1 1  37 5  2 31  4  4  2                  9 65  1 12237 534 2
9 65  1 1 Z42  2 31  4 4        6                             1       9 65  1 12242 615 0
31   1         50 261  9 65  1 1  42 6  2 31  4  5  0                  9 65  1 12242 625 0
40 242         45 245  9 65  1 1  42 6  2 31  4  4  1                  9 65  1 12242 634 1
9 65  1 1 Z47  2 31  4 4        7                             0       9 65  1 12247 715 0
31   1         38 261  9 65  1 1  47 7  2 31  4  5  0                  9 65  1 12247 725 0
9 65  1 1 Z47  2 31  4 4        8                             1       9 65  1 12247 815 0
38   1         50 261  9 65  1 1  47 8  2 31  4  5  0                  9 65  1 12247 825 0
42 240         50 245  9 64  1 1  47 8  2 31  4  4  1                  9 65  1 12247 834 1
9 65  1 1 Z56  2 31  4 4        9                             0       9 65  1 12256 915 0
34   1         46 261  9 65  1 1  56 9  2 31  4  5  0                  9 65  1 12256 925 0
```

ONE-INCH-THICK HORIZONTALLY SAWED BOARDS, LISTING FROM TAPE 20 (A382675, figure 8)

```
9 65  1 1 Y27  2 31  4 4        1                             0       9 65  1 12127 115 0
30   1         50 261  9 65  1 1  27 1  2 31  4  5  0                  9 65  1 12127 125 0
9 65  1 1 Y54  2 31  4 4        2                             1       9 65  1 12154 215 0
30   1         50 261  9 65  1 1  54 2  2 31  4  5  0                  9 65  1 12154 225 0
48 240         50 245  9 65  1 1  54 2  2 31  4  4  1                  9 65  1 12154 234 1
```

4.5 Second Sort

The first sort is repeated to eliminate changes in the card image sequence caused by program 4150. The major to minor sorts are the same as the sort outlined in section 4.3 After sorting, the data are stored in scratch tape 9 (fig. 8).

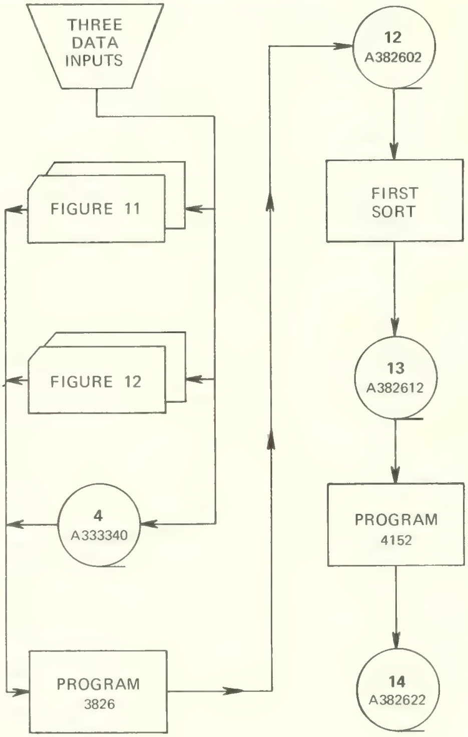
4.6 Program 4151

This program separates the 1- and 2-inch-thick boards to allow the efficient use of the computer with program YIELD. In the program as listed, it is assumed that both 1- and 2-inch-thick boards are being sawed. Sawing methods 1, 2, and 3 are used to saw only 1-inch-thick boards, and sawing methods 4 and 5 are used to saw only 2-inch-thick boards. Since different cutting lists (product specifications) may be used for 1- and 2-inch-thick boards in program YIELD, these two outputs are separated. By reading the sawing method field, the program makes this separation. Scratch tape 9 is divided by program 4151 into tape 10 (A382635) (1-inch-thick boards), and tape 11 (A382636) (2-inch-thick boards) as shown in figure 8. A sample listing for tape 10 is shown in figure 9.

5.0 Conversion of Vertically Oriented Data to Horizontally Oriented Data

In this operation, the vertically oriented data (there are Y and X axis locations for each defect on all Z planes) are converted to horizontally oriented data (there will be Z and X axis locations for each defect on the required Y planes), so that the horizontal sawing can be done efficiently. In horizontal sawing, the Y plane is specified, and the Z and X axis locations for the board outline and the defect outlines falling on this plane must be determined. So a conversion process is required, because all possible Y-plane values are not in the log model (3.4). The process logic is shown in figure 10.

Figure 10.—Vertical data conversion program logic steps.



5.1 Starting the Conversion

One input tape, the glass log models (3.4), and two card decks (5.2 and 5.3) are used for the vertical data conversion. The instructions on how to record the data for these two card decks are explained in the following paragraphs. With the input tape and with the two card decks, the data conversion is made under the control of the JCL.

5.2 Y-axis Selection List

The Y-axis selection list is used to limit the data conversion and to improve the computer efficiency. The list is made from the sawing instructions. This is done so that only those Y planes that will be subsequently required in the vertical sawing will go through the conversion program. The program as listed assumes that only five different Y planes will be required for the 1-inch-thick horizontal boards and that only four additional Y axes will be needed for the 2-inch-thick horizontal boards. This differentiation is done for convenience in writing down the selection list. One selection list card is required for each log diameter. For all sawing methods, all of the Y planes from the sawing instructions with plane control 1 (2.2) are written into the selection list. The Y-plane values are written in I2 fields with the smallest Y plane in the first field and the largest in the last field. Similar Y-plane values are not repeated. This procedure is illustrated in figure 11 for the 9-inch-diameter log used in previous illustrations.

Log Dia.		One Inch Boards										Two Inch Boards							
		1st		2nd		3rd		4th		5th		1st		2nd		3rd		4th	
Card Columns																			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	9	2	7	5	4														

Figure 11.—Y-plane selection list.

5.3 Y-plane Search Limits List

The Y-plane search limits list is made from the sawing instructions and further improves the computer efficiency by confining the search to specific limits. For instance, suppose that a particular defect in the log model went through two Z planes and the outline of the defect on each Z plane was as follows: lower left corner (Z40, Y35, and X250) and upper right corner (Z40, Y45, and X260) on the first Z plane; and lower left corner (Z41, Y38, and X250) and upper right corner (Z41, Y46, and X260) on the second Z plane. Now suppose that the search list called for plane Y36. The Z and Y values are found by a search for the two card images that fall on each side of the required Y plane. In this case,

Figure 12.—Sample data sheet for Y-plane search limits.

LOG DIA.		ONE INCH BOARDS																				TWO INCH BOARDS															
		1st				2nd				3rd				4th				5th				1st				2nd				3rd				4th			
		LOWER		UPPER		LOWER		UPPER		LOWER		UPPER		LOWER		UPPER		LOWER		UPPER		LOWER		UPPER		LOWER		UPPER		LOWER		UPPER		LOWER		UPPER	
Card Columns 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
	9	2	5	3	0	5	2	5	6																												

search limits of Y30 to Y40 might be appropriate, although search limits of Y34 to Y39 would be more efficient.

One search limit card is required for each search list card. The search limits must be specified for each Y plane in the search list and must be in the order given in the search list. Two fields are used, with the lower value preceding the upper value. The search limits are rather arbitrary. Wide search limits do not decrease the accuracy but they do increase the search time. Limits should be wide on the Y planes in the middle of the log, but they can be narrow on Y planes at the top and bottom of the log. Figure 12 gives the form in which the limits are written, with the 9-inch-diameter log values as an example.

5.4 Program 3826

Three operations are performed in this program: (1) data are taken from the glass log model according to the selection lists, (2) the Z- and Y-axis values for each defect are interchanged, and (3) the resulting upper left and lower right corner locations for each defect are changed to the required lower left and upper right corner locations.

The search begins with the lower limit (fig. 12) for the log diameter given in the search list. The card images are compared on the Y-axis field until the Y axis closest to the required Y plane is found. This card image and its pair are retained. There will be two such "closest" card image pairs, one for the low Z-axis value and one for the high Z-axis value. The search goes on for each board outline and for each defect by type and serial number within each log. The retained card image of the nearest Y-axis value is changed to the required Y-plane value.

The board and defect outlines are now in the required Y plane, but the vertical-sawing program assumes that the surface of the board is in the Z plane. To use the vertical-sawing program, the Y-plane values have to be put into the Z plane. So the Y-axis value and the Z-axis value on each card image are transposed. It is as if figure 4 had been changed so that columns 11 to 15 were Y axes and columns 16 to 20 were Z axes.

The board outline and defect outlines are now described by their upper left corners and lower right corners. The Z-axis values, now in the Y-axis field, are subtracted from the maximum value of the Z axis in the three dimensional coordinate system. This now gives the lower left corner and the upper right corner of the board or defect outline.

The data from program 3826 are stored on scratch tape 12 (fig. 10).

5.5 Sorting

The data are sorted so that they will be in the correct sequence for horizontal sawing. This sort, by increasing size of the variables from the major to minor sorts, is: log diameter, log length, log serial number, log species, Z axis, defect type, defect serial number, Y axis, and X axis. It should be remembered that the card images on tape 12 are arranged according to the field listing shown in figure 4. The Z axis is in card columns 11 to 15, and the Y axis is in card columns 16 to 20. The sorted data are put on scratch tape 13 (fig. 10).

5.6 Program 4152

Two operations are performed in this program: (1) the defects lying outside the board outlines are rejected, and (2) the defects lying across the board outlines are truncated. When the vertical data conversion initially found a defect beyond the board outlines, this defect was processed with the rest. This happens for some knots that extend beyond the side of the log. Program 4152 rejects this type of defect. When a defect lies across a board outline edge, this program truncates the defect so that the edge of the defect and the edge of the board are the same. The data from program 4151 are put on tape 14 (fig. 10).

6.0 Horizontal Sawing

The vertical sawing programs are used to perform the horizontal sawing. In this way, only one sawing program had to be written.

6.1 Starting the Horizontal Sawing

Two input tapes are used for the horizontal sawing: the output tape from the vertical data conversion and the tape containing the horizontal sawing instructions. The sawing instructions are on tape 15 (2.3), with WDPC catalog number A382651. Tape 14 (5.6) from the vertical data conversion program, with WDPC catalog number A382622, contains the board outline and defect data.

6.2 Horizontal Sawing

The horizontal sawing programs and sorting statements are the same as the vertical sawing programs and sorting statements. The process logic is the same and is shown in figure 8. Because the input and output tape numbers are different, the JCL statements must be changed. The scratch tape reel numbers will remain as they were during the vertical sawing. Programs 4149, 4150, and 4151 do not have to be recompiled and the sorting statements remain the same.

6.3 Horizontal Sawing Output

The output of the horizontal sawing is divided into two parts: (1) the 1-inch-thick boards, from sawing methods 1, 2, and 3 are put on tape 20 (WDPC catalog number A382675) and (2) the 2-inch-thick boards, from sawing methods 4 and 5, are put on tape 21 (WDPC catalog number A382676). An example of the listing from tape 20, for the 9-inch diameter log, is shown in figure 9.

COMPUTER PROGRAM YIELD

Simulated sawing is completed by using the output of program DEFECT as the input for program YIELD. The output of program DEFECT is shown in figure 9. The first 80 columns of this output are sufficient for program YIELD. There will be one set of horizontal boards and one set of vertical boards from each log in the model sawed by each method (technique). Program YIELD simulates the ripping and trimming of these boards to products whose widths and lengths are given in the product specifications. The product specifications of grade and board thickness have been taken into account in program DEFECT (2.2); so the product (cuttings) coming from program YIELD is shown by grade, thickness, length, and width for all boards from each log in the model sawed by each method.

Program YIELD was written at the Forest Products Laboratory, Madison, Wis., and is explained in a separate publication.[3] The reader is referred to this publication for instructions in the use of the program. Program YIELD was written in Fortran 63 language and the listing published by the Forest Products Laboratory is operational on the Control Data 3600 computer. A listing in Fortran IV for operation on the IBM 360/40 is available from the author of this paper.

FURTHER APPLICATION

The sawmill simulation algorithm can be made more general, but changes and additions will be required in program DEFECT. However, the log model will not have to be changed when new sawing problems are being investigated. Some of these changes or additions to the program are suggested in the following paragraphs.

The program listed will handle a maximum log diameter of 20 inches and a maximum log length of 20 feet. Larger logs can be used if changes in the three-dimensional grid system (diameter and length fields) of program 3826 are made. For example, the log-identification fields, shown in figure 4, can describe a 99-inch diameter by 999-inch (83.3-foot) long log when 1-inch diameter classes are used. If the model's increment system is changed from other than $\frac{1}{4}$ inch, minor changes must be made in sections **1.5** and **5.4**.

Boards can be sawed vertically (as the original sawing was done in making the log model) or horizontally. But another program will have to be written if boards are to be sawed at other angles. This can be done with a rotation program if the angle of rotation is known or assumed. The rotation program would have four parts: (1) Each card image in the interpolated glass log model, tape 4, figure 5, would have its Z- and Y-axis values converted to a polar coordinate form. The center of rotation for the polar coordinate form would be the center of the Z- and Y-axis grid. (2) The angle of rotation would be added to the polar form angle. (3) The polar form would then be converted back to the cartesian coordinate form. (4) The Z- and Y-axis values would be rounded off to the nearest increment. The X-axis values would not have to be changed. The rotated glass log model would then be manipulated by the programs to saw vertical and horizontal boards.

Boards are sawed parallel to the central axis of the log. If boards are to be sawed parallel to the outside of the tapered logs, another program would have to be written. To perform taper sawing, the log model would have to be distorted so that the outside of the log would be parallel to the central axis of the log.

A program would have to be written to perform the distortion. The program would spread out the small end of the log, and then the vertical sawing could be done with regular sawing instructions for vertical boards. To saw horizontal boards, the glass log would have to be rotated 90 degrees; and the spreading-out and vertical sawing would be repeated.

There are no computer programs that will take the output data from program DEFECT and find the board grade and footage. Such a grading program for standard hardwood lumber is under development at the U. S. Forest Products Laboratory.

APPENDIX

```
C       PALLET LUMBER STUDY
C        PROJECT NUMBER 530719-9201
C        PROGRAM NUMBER 3333
00501 FORMAT(80I1)
00101 FORMAT(24H1DEFECT TYPE GREATER 999)
00301 FORMAT(16H1BOTH YS,YE ZERO)
00001 FORMAT(I8,I2,2I5,I6,5X,2I3)
00008 FORMAT(I8,I2,2I5,I6,I5,2I3)
00090 FORMAT(I8,I2,2I5,I6,I5,I3)
   200FORMAT(1H0,20X,10HEND OF JOB,5X,'INPUT COUNT =',I5,5X,'OUTPUT COUN
     1T =',I6)
      DIMENSION FLO(7,3),IFLO(7,3),AFLO(7,3)
      CALL SLITE (0)
      INPUT = 0
      IOUT = 0
01101 ISERL = 0
      CALL SLITET (1,ISL)
      GO TO (114,116), ISL
  114 READ (5,1) ((IFLO (I,J),I=1,7),J=2,3)
      INPUT = INPUT + 2
      GO TO 118
  116 READ (5,1) ((IFLO(I,J),I=1,7),J=1,3)
      INPUT = INPUT + 3
  118 M=1
      GO TO 9
00006 READ (5,1) (IFLO(I,3),I=1,7)
      INPUT = INPUT + 1
      IF (IFLO(6,3)-5) 125,110,110
  110 IF (IFLO(6,1)-5) 112,125,125
  112 CALL SLITE (1)
      CALL SLITE (2)
      GO TO 200
  125 M=2
11111 ISTOP=1
      LDIAM=2
      IF(IFLO(6,3)-999)9,200,99
00009 LDIAM=1
      IF(IFLO(2,3)-88)1102,200,1102
01102 DO 17 J=1,3
      DO 16 I=3,4
00016 FLO(I,J)=IFLO(I,J)-40
      DO 17 I=3,5
00017 AFLO(I,J)=IFLO(I,J)
      GO TO (13,7),M
00013 RA2=(FLO(4,1)**2+FLO(3,1)**2+FLO(4,3)**2+FLO(3,3)**2)/2.
00007 IZ=IFLO(3,3)-IFLO(3,1)-1
      IF(IZ)11,11,700
00011 DO 55 J=1,2
      ISERL = ISERL + 1
      IF(IFLO(6,1) - 5) 51,52,51
00051 WRITE (4,8) (IFLO(I,J),I=1,5),ISERL,
     1(IFLO(I,J),I=6,7)
      IOUT = IOUT + 1
      GO TO 55
00052 WRITE (4,90) (IFLO(I,J),I=1,5),ISERL,IFLO(6,J)

      IOUT = IOUT + 1
00055 CONTINUE
```

CONTINUED

```
00012 DO 14 I=1,7
00014 IFLO(I,1)=IFLO(I,3)
      READ (5,1) ((IFLO(I,J),I=1,7),J=2,3)
      INPUT = INPUT + 2
22222 ISTOP = 1
      LDIAM=2
      IF(IFLO(6,3)-999)9,200,99
00700 ISERL=ISERL+1
      IF(IFLO(6,1) - 5) 27,28,27
00027 WRITE (4,8) (IFLO(I,1),I=1,5),ISERL,(IFLO(I,1),I=6,7)
      IOUT = IOUT + 1
      GO TO 10
00028 WRITE (4,90) (IFLO(I,1),I=1,5),ISERL, IFLO(6,1)
      IOUT = IOUT + 1
00010 DO 2 K=1,IZ,1
      IZR=IFLO(3,1)+K
      ZRLIN=IZR
      IF(IFLO(6,1)-5) 3,5,3
00005 ZRRAD2=(IZR-40)**2
      RADICD=RA2-ZRRAD2
      IF(RADICD) 1600,1600,1601
01600 YR = 0
      GO TO 33333
01601 YR=SQRT(RADICD)
33333 ISTOP=2
      IF(FLO(4,1))50,41,49
00041 IF(FLO(4,3))50,49,49
   50 IY = ABS(40.5 - YR)
      GO TO 4
   49 IY = ABS(40.5 + YR)
      GO TO 4
00003 YR=AFLO(4,1)+((AFLO(4,1)-AFLO(4,3))/(AFLO(3,1)-AFLO(3,3)))*
     1(ZRLIN-AFLO(3,1))
      IY = ABS(YR + 0.5)
00004 X=AFLO(5,1)+((AFLO(5,1)-AFLO(5,3))/(AFLO(3,1)-AFLO(3,3)))*
     1(ZRLIN-AFLO(3,1))
      IX = ABS(X + 0.5)
      ISERL = ISERL + 1
      IF(IFLO(6,1)-5)22,21,22
00022 WRITE(4,8)(IFLO(I,1),I=1,2),IZR,IY,IX,ISERL,(IFLO(I,1),I=6,7)
      IOUT = IOUT + 1
      GO TO 2
00021 WRITE(4,90)(IFLO(I,1),I=1,2),IZR,IY,IX,ISERL,IFLO(6,1)
      IOUT = IOUT + 1
00002 CONTINUE
00045 DO 46 I=1,7
      IFLO(I,1)=IFLO(I,2)
00046 IFLO(I,2)=IFLO(I,3)
      GO TO 6
00200 DO 66 J=1,2
      ISERL = ISERL + 1
      IF(IFLO(6,1)-5)31,32,31
00031 WRITE (4,8) (IFLO(I,J),I=1,5),ISERL,
     1(IFLO(I,J),I=6,7)
      IOUT = IOUT + 1
      GO TO 66
00032 WRITE (4,90) (IFLO(I,J),I=1,5),ISERL,IFLO(6,J)
      IOUT = IOUT + 1
00066 CONTINUE
      CALL SLITET (2,ISL)
      GO TO (122,120), ISL
```

CONTINUED

Program 3333. — Continued

```
  122 DO 124 I=1,7
  124 IFLO(I,1) = IFLO(I,3)
  120 GO TO (1101,1105),LDIAM
01105 III=9
      WRITE(4,501) (III,I=1,80)
      IOUT = IOUT + 1
      WRITE (6,20) INPUT, IOUT
00220 STOP 99999
00099 GO TO (100,300),ISTOP
00100 WRITE (6,101)
      STOP 11111
00300 WRITE (6,301)
      STOP 33333
      END
```

```
C      PALLET LUMBER STUDY
C       JOB NUMBER 530719-9201
C       PROGRAM NUMBER 3826
C       WRITTEN BY ELGIN G. FRY
C       DATE WRITTEN  DECEMBER 13,1966
C       WDPC--SRS
C
     0DIMENSION METH2(20,5), METH5(20,4), KLOW2(20,5), KUP2(20,5),
     1KLOW5(20,4), KUP5(20,4)
      I1 = 1
      I2 = 2
      DO 4 I=1,20
      DO 2 J=1,5
      KLOW2(I,J) = 0
      KUP2(I,J) = 0
    2 METH2(I,J) = 0
      DO 3 J=1,4
      KLOW5(I,J) = 0
      KUP5(I,J) = 0
    3 METH5(I,J) = 0
    4 CONTINUE
      DO 8 I=8,20
      READ (5,6) (METH2(I,K),K=1,5), (METH5(I,K),K=1,4)
    6 FORMAT(2X,9I2)
    8 CONTINUE
      DO 12 I=8,20
     0READ (5,10) (KLOW2(I,J), KUP2(I,J), J=1,5), (KLOW5(I,J),
     1KUP5(I,J), J=1,4)
   10 FORMAT(2X,18I2)
   12 CONTINUE
   14 READ (1,16) KDIAM, LEN, NO, KSP, KZPL, KYAXIS, KXAXIS, ITYPE, INO
   16 FORMAT(I2,I3,I3,I2,2I5,I6,5X,2I3)
      IF (KDIAM-99) 18,40,40
   18 READ (1,20) JYAXIS, JXAXIS
   20 FORMAT(15X,I5,I6)
      KZPL = 80 - KZPL
      DO 28 J=1,5
      IF (METH2(KDIAM,J)) 28,28,22
   22 IF (KYAXIS-KLOW2(KDIAM,J)) 28,24,24
```

CONTINUED

```
24 IF (KYAXIS-KUP2(KDIAM,J)) 26,26,28
260WRITE (2,27) KDIAM, LEN, NO, KSP, KZPL, METH2(KDIAM,J), KXAXIS,
  1I1, ITYPE, INO
27 FORMAT(I2,I3,I3,I2,2I5,I6,I5,2I3)
  0WRITE (2,27) KDIAM, LEN, NO, KSP, KZPL, METH2(KDIAM,J), JXAXIS,
  1I2, ITYPE, INO
28 CONTINUE
   DO 46 J=1,5
   IF (METH2(KDIAM,J)) 46,46,41

41 IF (JYAXIS-KLOW2(KDIAM,J)) 46,42,42
42 IF (JYAXIS-KUP2(KDIAM,J)) 44,44,46
440WRITE (2,27) KDIAM, LEN, NO, KSP, KZPL, METH2(KDIAM,J), KXAXIS,
  1I1, ITYPE, INO
  0WRITE (2,27) KDIAM, LEN, NO, KSP, KZPL, METH2(KDIAM,J), JXAXIS,
  1I2, ITYPE, INO
46 CONTINUE
29 DO 36 J=1,4
   IF (METH5(KDIAM,J)) 36,36,30
30 IF (KYAXIS-KLOW5(KDIAM,J)) 36,32,32
32 IF (KYAXIS-KUP5(KDIAM,J)) 34,34,36
340WRITE (2,27) KDIAM, LEN, NO, KSP, KZPL, METH5(KDIAM,J), KXAXIS,
  1I1, ITYPE, INO
  0WRITE (2,27) KDIAM, LEN, NO, KSP, KZPL, METH5(KDIAM,J), JXAXIS,
  1I2, ITYPE, INO
36 CONTINUE
   DO 56 J=1,4
   IF (METH5(KDIAM,J)) 56,56,51
51 IF (JYAXIS-KLOW5(KDIAM,J)) 56,52,52
52 IF (JYAXIS-KUP5(KDIAM,J)) 54,54,56
540WRITE (2,27) KDIAM, LEN, NO, KSP, KZPL, METH5(KDIAM,J), KXAXIS,
  1I1, ITYPE, INO
  0WRITE (2,27) KDIAM, LEN, NO, KSP, KZPL, METH5(KDIAM,J), JXAXIS,
  1I2, ITYPE, INO
56 CONTINUE
38 GO TO 14
40 WRITE (2,16) KDIAM, LEN, NO, KSP
   STOP
   END
```

```
C     PALLET LUMBER STUDY
C      JOB NUMBER 530719-9201
C      PROGRAM NUMBER  4149
C      WRITTEN BY ELGIN G. FRY
C      WDPC--SRS
C
      DIMENSION METH(700,10), KOUNT(5,40)
      I1 = 1
      I2 = 2
      I3 = 3
      INPUT = 0
      IOUT = 0
      KSW1 = 0
      KSW2 = 0
      DO 1  I=1,5
      DO 1  J=1,40
    1 KOUNT(I,J) = 0
      DO 4  I=1,700
      READ (5,2) (METH(I,J), J=1,10)
    2 FORMAT(I2,4X,I2,I3,2I2,3I3,10X,I1,I3)
      IF (METH(I,1)-99) 4,6,6
    4 CONTINUE
    6 NN= I - 1
      WRITE (6,7) NN
    7 FORMAT(1H0,'END OF SAWING METHOD TAPE',I5,1X,'RECORDS READ')
    8 READ (4,10) KD, LEN, LOG, KSP, KZ, KY, KX, KTYPE, KNO
   10 FORMAT(I2,I3,I3,I2,2I5,I6,5X,2I3)
      INPUT = INPUT + 1
      ISW = 0
      IF (KD-99) 12,100,100
   12 READ (4,14) JZ, JY, JX
   14 FORMAT(10X,I5,I5,I6)
      INPUT = INPUT + 1



   26 DO 128 I=1,NN
      IF (METH(I,1)-KD) 99,27,99
   27 IF (METH(I,5) - 1) 28,28,104
  104 IF (ISW) 105,105,28
  105 KTEMP = KY
      KY = KZ
      KZ = KTEMP
      KTEMP = JY
      JY = JZ
      JZ = KTEMP
      ISW = 1
   28 IF (METH(I,6)-KY) 99,30,99
   30 IF (KTYPE-5) 32,40,40
   32 IF (METH(I,9) - KTYPE) 34,34,99
   34 IF (METH(I,9) - 4) 40,36,40
   36 IF ((JZ-KZ)-4) 38,38,40
   38 IF ((JX-KX)-4) 99,99,40
   40 IF (METH(I,7)-KZ) 44,44,42
   42 KTEMP = KZ
      KSW1 = 1
      KZ = METH(I,7)
   44 IF (METH(I,8)-JZ) 46,48,48
   46 JTEMP = JZ
      KSW2 = 1
      JZ = METH(I,8)
   48 IF (KTYPE-5) 82,50,50
   50 IF (METH(I,4)-3) 52,52,64
```

CONTINUED

Program 4149. — Continued

```
520WRITE (1,54) KZ, KX, JZ, JX, KD, LEN, LOG, KSP, KY, METH(I,10),
   1METH(I,4), METH(I,2), METH(I,3), KTYPE, KNO, KD, LEN, LOG, KSP,
   2METH(I,4), METH(I,5), METH(I,6), METH(I,10), I2, KTYPE, KNO
540FORMAT(I3,I4,8X,I2,I4,I3,I3,I3,I2,I4,I2,I3,I3,I3,I3,I3,27X,
   1I2,2I3,I2,I1,I1,2I2,2I1,I2)
    IOUT = IOUT + 1
    IF (METH(I,5)-2) 60,56,56
56  M = METH(I,4)
    N = METH(I,10)
   0WRITE (1,58) KD, LEN, LOG, KSP, METH(I,6), METH(I,4), METH(I,2),
   1METH(I,3), METH(I,9), METH(I,10),KOUNT(M,N),KD, LEN, LOG, KSP,
   2METH(I,4), METH(I,5), METH(I,6), METH(I,10), I1, KTYPE, KNO
580FORMAT(I2,I3,I3,I2,1X,1HZ,I2,I3,I3,I3,I2,9X,I2,32X,I4,8X,
   1I2,2I3,I2,I1,I1,2I2,2I1,I2)
    IOUT = IOUT + 1
    GO TO 80
60  M = METH(I,4)
    N = METH(I,10)
    WRITE (1,62) KD, LEN, LOG, KSP, METH(I,6), METH(I,4), METH(I,2),
   1METH(I,3), METH(I,9), METH(I,10),KOUNT(M,N),KD, LEN, LOG, KSP,
   2METH(I,4), METH(I,5), METH(I,6), METH(I,10), I1, KTYPE, KNO
620FORMAT(I2,I3,I3,I2,1X,1HY,I2,I3,I3,I3,I2,9X,I2,32X,I4,8X,
   1I2,2I3,I2,I1,I1,2I2,2I1,I2)
    IOUT = IOUT + 1
    GO TO 80
640WRITE (1,54) KZ, KX, JZ, JX, KD, LEN, LOG, KSP, KY, METH(I,10),
   1METH(I,4), METH(I,2), METH(I,3), KTYPE, KNO, KD, LEN, LOG, KSP,
   2METH(I,4), METH(I,5), METH(I,6), METH(I,10), I2, KTYPE, KNO
    IOUT = IOUT + 1
    IF (METH(I,5)-2) 70,66,66
66  M = METH(I,4)
    N = METH(I,10)
   0WRITE (1,58) KD, LEN, LOG, KSP, METH(I,6), METH(I,4), METH(I,2),
   1METH(I,3), METH(I,9), METH(I,10),KOUNT(M,N),KD, LEN, LOG, KSP,
   2METH(I,4), METH(I,5), METH(I,6), METH(I,10), I1, KTYPE, KNO
    IOUT = IOUT + 1


    GO TO 80
70  M = METH(I,4)
    N = METH(I,10)
    WRITE (1,62) KD, LEN, LOG, KSP, METH(I,6), METH(I,4), METH(I,2),
   1METH(I,3), METH(I,9), METH(I,10),KOUNT(M,N),KD, LEN, LOG, KSP,
   2METH(I,4), METH(I,5), METH(I,6), METH(I,10), I1, KTYPE, KNO
    IOUT = IOUT + 1
80  KOUNT(M,N) = 0
    GO TO 99
82  M = METH(I,4)
    IF (M-3) 84,84,88
840WRITE (1,86) KZ, KX, JZ, JX, KD, LEN, LOG, KSP, METH(I,6),
   1METH(I,10), METH(I,4), METH(I,2), METH(I,3), KTYPE, KNO, KD, LEN,
   2LOG, KSP, METH(I,4), METH(I,5), METH(I,6), METH(I,10), I3,
   3KTYPE, KNO
860FORMAT(I3,I4,8X,I2,I4,I3,I3,I3,I2,I4,I2,I3,I3,I3,I3,I3,27X,
   1I2,2I3,I2,I1,I1,2I2,2I1,I2)
    IOUT = IOUT + 1
    GO TO 90
880WRITE (1,86) KZ, KX, JZ, JX, KD, LEN, LOG, KSP, METH(I,6),
   1METH(I,10), METH(I,4), METH(I,2), METH(I,3), KTYPE, KNO, KD, LEN,
   2LOG, KSP, METH(I,4), METH(I,5), METH(I,6), METH(I,10), I3,
   3KTYPE, KNO
```

CONTINUED

Program 4149. — Continued

```
      IOUT = IOUT + 1
   90 N = METH(I,10)
      KOUNT(M,N) = KOUNT(M,N) + 1
   99 IF (KSW1) 124,124,122
  122 KZ = KTEMP
      KSW1 = 0
  124 IF (KSW2) 128,128,126
  126 JZ = JTEMP
      KSW2 = 0
  128 CONTINUE
      GO TO 8
  100 WRITE (1,97) KD, LEN, LOG, KSP, LOG, LOG
   97 FORMAT(80X,I2,2I3,I2,2I3)
      IOUT = IOUT + 1
      WRITE (6,102) INPUT, IOUT
  1020FORMAT(1H0,10HEND OF RUN,5X,'INPUT COUNT =',I6,5X,'OUTPUT COUNT ='
     1,I6)
      STOP
      END
```

```
C     PALLET LUMBER STUDY
C      PROJECT NUMBER 530719-9201
C      PROGRAM NUMBER 4150
      DIMENSION HEADER(25), ALPHA(25), DEFECT(25)
    20READ (1,4) (HEADER(I),I=1,17), KOUNT, KD, (HEADER(J),J=18,22)
    4 FORMAT(17A4,I4,8X,I2,4A4,A2)
      IF (KD-99) 6,40,40
    6 READ (1,8) KZ, KX, JZ, JX, (ALPHA(I),I=1,20)
    8 FORMAT(I3,I4,8X,I2,I4,A3,19A4)
      WRITE (2,8) KZ, KX, JZ, JX, (ALPHA(I),I=1,20)
      N = KOUNT
      IF (N) 10,10,12
   10 WRITE (2,4) (HEADER(I),I=1,17), KOUNT, KD, (HEADER(J),J=18,22)
      GO TO 2
   12 DO 34 I=1,N
      READ (1,13) NZ, NX, MZ, MX, (DEFECT(J),J=1,6), METH, (DEFECT(J),
     1J=7,20)
   13 FORMAT(I3,I4,8X,I2,I4,6A4,I2,A1,13A4)
      IF (NZ-JZ) 14,14,30
   14 IF (NZ-KZ) 16,18,18
   16 NZ = KZ
   18 IF (MZ-KZ) 30,20,20
   20 IF (MZ-JZ) 24,24,22
   22 MZ = JZ
   24 IF (METH-4) 28,25,28
   25 IF (MZ-NZ) 30,30,26
   26 IF ((MZ-NZ)-4) 27,27,28
   27 IF ((MX-NX)-4) 30,30,28
   280WRITE (2,13) NZ, NX, MZ, MX, (DEFECT(J),J=1,6), METH, (DEFECT(J),
     1J=7,20)
      GO TO 34
   30 KOUNT = KOUNT - 1
   34 CONTINUE
      GO TO 10
   40 WRITE (2,4) (HEADER(I),I=1,17), KOUNT, KD, (HEADER(J),J=18,22)
      STOP
      END
```

```
C     PALLET LUMBER STUDY
C      PROJECT NUMBER 530719-9201
C      PROGRAM NUMBER 4151
      DIMENSION ALPHA(26)
    2 READ (1,4) (ALPHA(I),I=1,23), K, (ALPHA(I),I=24,26)
    4 FORMAT(22A4,A2,I1,A1,2A4)
      IF (K-9) 6,12,12
    6 IF (K-3) 8,8,10
    8 WRITE (2,4) (ALPHA(I),I=1,23), K, (ALPHA(I),I=24,26)
      GO TO 2
   10 WRITE (3,4) (ALPHA(I),I=1,23), K, (ALPHA(I),I=24,26)
      GO TO 2
   12 WRITE (2,4) (ALPHA(I),I=1,23), K, (ALPHA(I),I=24,26)
      WRITE (3,4) (ALPHA(I),I=1,23), K, (ALPHA(I),I=24,26)
      STOP 999
      END
```

```
C     PALLET LUMBER STUDY
C      JOB NUMBER 530719-9201
C      PROGRAM NUMBER 4152
C      WRITTEN BY ELGIN G. FRY
C      DATE WRITTEN  DECEMBER 12, 1966
C      WDPC--SRS
C
      IZ1 = 80
      IX1 = 256
      IZ2 = 0
      IX2 = 0
      CALL SLITE (1)
    2 READ (1,4) KD, LNG, LOG, KSP, KZPL, KYPL, KXAX, KTYPE, KNO
    4 FORMAT(I2,2I3,I2,2I5,I6,5X,2I3)
      IF (KD-99) 6,40,40
    6 READ (1,8) JZPL, JXAX
    8 FORMAT(10X,I5,5X,I6)
      CALL SLITET (1,ISL)
      GO TO (24,10), ISL
   10 IF (KD-ND) 40,12,40
   12 IF (LNG-NNG) 40,14,40
   14 IF (LOG-NOG) 40,16,40
   16 IF (KSP-NSP) 40,18,40
   18 IF (KYPL-NYPL) 40,20,40
   20 IF (KTYPE-NTYPE) 40,22,40
   22 IF (KNO-NNO) 40,24,40
   24 IF (KXAX-IX1) 26,27,27
   26 IX1 = KXAX

   27 IF (KZPL-IZ1) 28,30,30
   28 IZ1 = KZPL
   30 IF (JXAX-IX2) 34,34,32
   32 IX2 = JXAX
   34 IF (JZPL-IZ2) 38,38,36
   36 IZ2 = JZPL
   38 ND = KD
```

CONTINUED

Program 4152. — Continued

```
      NNG = LNG
      NOG = LOG
      NSP = KSP
      NYPL = KYPL
      NTYPE = KTYPE
      NNO = KNO
      GO TO 2
   40 WRITE (2,4) ND, NNG, NOG, NSP, IZ1, NYPL, IX1, NTYPE, NNO
      WRITE (2,4) ND, NNG, NOG, NSP, IZ2, NYPL, IX2, NTYPE, NNO
      IF (KD-99) 42,44,44
   42 IZ1 = 80
      IZ2 = 0
      IX1 = 256
      IX2 = 0
      GO TO 24
   44 WRITE (2,4) KD, LNG, LOG, KSP
      STOP
      END
```

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THE FOREST SERVICE of the U. S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

Cutting Strategies & Timber Yields

FOR UNBALANCED EVEN-AGED NORTHERN HARDWOOD FORESTS

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by William B. Leak
and Stanley M. Filip

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Cutting Strategies & Timber Yields

FOR UNBALANCED EVEN-AGED NORTHERN HARDWOOD FORESTS

CUTTING STRATEGIES FOR THE UNREGULATED FOREST

THE EVEN-AGED HARDWOOD forest, with a poorly balanced distribution of age-classes, can cause perplexing problems during the first rotation. What is the best cutting strategy to follow? By using linear programming, we developed some cutting strategies that maximize board-foot production and produce a balanced age distribution by the end of the first rotation.

We developed the strategies for four hypothetical northern hardwood forests with different unbalanced age distributions. Although these strategies may be used for forest lands with conditions similar to those assumed in this study, we urge that the linear programming techniques described in this paper be used to develop strategies tailored to particular forests and to particular management objectives.

THE PROBLEM

Even-aged management, using some form of clearcutting, is gradually becoming accepted in the northern hardwood forests of New England, especially where a high proportion of intolerant and intermediate species are desired.

On forest land committed to long-term timber production by even-aged methods, sustained-yield management by area control usually is the objective. Briefly, this is accomplished by building up a uniform distribution of age classes, and then harvesting roughly an equal acreage from the oldest age class during each operating cycle, producing a fairly steady flow of timber products. Of course, year-to-year fluctuations in cutting are required to meet market conditions.

However, most northern hardwood forests exhibit a poorly balanced age-class distribution: Some age classes predominate, while others account for only a few acres, or are absent. On some forests, a backlog of old-growth, uneven-aged timber is present.

Where a poorly balanced distribution of age classes exists, the first step toward developing a regulated even-aged forest is to devise an appropriate cutting strategy for the first rotation—the adjustment period. Generally, this cutting strategy should (1) mold the forest into a reasonably well-balanced distribution of age classes by areas, (2) maintain adequate or specified volume yields throughout the adjustment period, and (3) optimize forest production in either volume or monetary units.

The problem of developing appropriate cutting strategies has been recognized by forest managers for some time. However, two developments have recently made it possible to devise such strategies for northern hardwoods in New England. First, a series of investigations over the last few years have shown how linear programming, and related analytical techniques, can be used to maximize forest production while maintaining specified limits on area and volume *(Coutu and Ellertsen 1960; Curtis 1962; Kidd 1966; Leak 1964; Liittschwager and Tcheng 1967; Loucks 1964; McConnen 1967;* and *Paine 1966).* Second, tables of volume yield have been developed recently for even-aged northern hardwood stands in New England for both managed and unmanaged conditons. Although tentative, these yield tables provide, for the first time, a reasonable basis for projecting volume yields of northern hardwoods over a full rotation.

METHODS

Management Situations

In this study, we assumed four management situations, each characterized by a specified distribution of age classes (table 1). Management situation I has a roughly bell-shaped distribution of age classes, typical of some of the large ownerships in the northern hardwood region. The 40- to 60-year age class predominates among the even-aged stands, and there is a fairly large backlog of uneven-aged timber. Management situation II has gradually increasing acres by age classes and a backlog of uneven-aged timber. Situation III has gradually decreasing acres by age classes, with a backlog of uneven-aged timber. Situation IV has a distribution of age classes similar to that in situation III, but without the backlog of uneven-aged timber.

Because of the tolerance and longevity of many of the species, uneven-aged northern hardwood timber can be stored fairly well

Table 1.—*Percent of forest area in 20-year stand age classes for four management situations*

Stand age class (years)	Management situation			
	I	II	III	IV
	Percent	*Percent*	*Percent*	*Percent*
0 - 20	4	2	22	26
20 - 40	15	6	18	22
40 - 60	26	10	14	19
60 - 80	10	14	10	15
80 - 100	8	18	6	11
100 - 120	4	22	2	7
120 - 140	2	0	0	0
140 - 160	0	0	0	0
160 - 180	0	0	0	0
Uneven-aged	31	28	28	0

on the stump. So we assumed that the backlog of uneven-aged timber, if any, could be removed at any time during the first rotation.

We chose a 20-year operating cycle. This means that each stand in each management situation would be examined and considered for treatment once every 20 years.

For each management situation, we compared the yield under management with the yield under no management. When the forest was assumed to be under management, any even-aged stand that was not scheduled for clearcutting during an operating cycle was assumed to be commercially thinned; any uneven-aged stand that was not clearcut was assumed to be partially cut. Several precommercial thinnings also were assumed under management. When no management was assumed, clearcutting was the only treatment.

For both the managed and unmanaged conditions, we assumed the same rotation objective: a mean stand diameter of about 14 inches d.b.h. In northern hardwoods, which have a typical J-shaped diameter distribution, this mean diameter represents heavy sawtimber. This mean diameter is equivalent to rotation age of 160 to 180 years in unmanaged stands, and 120 to 140 years in managed stands. No stands were to be allowed to exceed the appropriate rotation age unless necessary to achieve a balanced age distribution. As the results will later illustrate, many stands had to be scheduled for cutting before rotation age.

Initially, the linear programming analysis was set up so that volume yields would increase, rather than drop, during each succeeding operating cycle. However, this restriction was eliminated because it placed an arbitrary limitation upon forest yields that might not be appropriate for many forest lands. However, it should be noted that volume yield restrictions of almost any kind can be built into this type of analysis if so desired.

Yield Tables

Yield estimates were adapted directly from the tables in *A Silvicultural Guide for Northern Hardwoods in the Northeast (Leak, Solomon, and Filip 1969).* Gross board-foot yields (International $1/4$-inch rule) in trees 10.5 inches and over for managed and unmanaged conditions are for an average site, site index 60 (base age 50), for sugar maple.

Thinning yields were developed from the stocking guides in the above-mentioned silvicultural guide. The amount of basal area required to reduce a stand from full stocking to recommended residual stocking was converted to board feet, using conversion factors applicable to New England.

When a forest was assumed to be under management, both the harvest yields per acre and the thinning yields per acre were assumed to increase steadily with each operating cycle from the unmanaged yields up to the managed yields.

Table 2 gives the harvest yield estimates used for unmanaged conditions. Table 3 gives the harvest yields for managed forests during the adjustment period. Table 4 shows the thinning yields from managed forests during the adjustment period. These yield figures are tentative and are subject to change as new information is obtained. However, these are the best estimates available at this time.

With an operating cycle shorter than 20 years, thinning yields from even-aged stands and partial-cutting yields from uneven-aged stands no doubt would be higher, but perhaps more costly to log. Harvest yields would be higher, as well.

Table 2.—*Clearcutting harvest yields for unmanaged northern hardwoods, for all operating cycles*

Age class	Yield per acre	Age class	Yield per acre
Years	*Board feet*	*Years*	*Board feet*
0-20	0	100-120	7,800
20-40	0	120-140	11,200
40-60	0	140-160	14,100
60-80	2,500	160-180	15,800
80-100	5,650	Uneven-aged	13,000

Table 3.—*Clearcutting harvest yields in board feet per acre for managed northern hardwoods (several precommercial thinnings assumed)*

Operating cycle (years)	Age class in years								
	0-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	Uneven-aged
0 - 20	0	0	0	2,500	5,650	7,800	11,200	14,100	13,000
20 - 40	—	0	0	3,650	6,538	8,950	11,967	14,483	13,000
40 - 60	—	—	0	4,800	7,426	10,100	12,734	14,866	13,000
60 - 80	—	—	—	5,950	8,314	11,250	13,501	15,249	13,000
80 - 100	—	—	—	5,950	9,200	12,400	14,268	15,632	13,000
100 - 120	—	—	—	5,950	9,200	13,550	15,035	16,015	13,000
120 - 140	—	—	—	5,950	9,200	13,550	15,800	16,400	13,000

Table 4.—*Thinning or partial cutting yields in board feet per acre for managed northern hardwoods (several precommercial thinnings assumed)*

Operating cycle (years)	Age class in years							
	0-20	20-40	40-60	60-80	80-100	100-120	120-140	Uneven-aged
0 - 20	0	0	0	1,250	2,250	3,000	4,000	5,000
20 - 40	—	—	—	1,617	2,563	3,330	4,204	5,000
40 - 60	—	—	—	1,984	2,876	3,660	4,408	5,000
60 - 80	—	—	—	2,350	3,189	3,990	4,612	5,000
80 - 100	—	—	—	2,350	3,500	4,320	4,816	5,000
100 - 120	—	—	—	2,350	3,500	4,650	5,020	5,000
120 - 140	—	—	—	2,350	3,500	4,650	5,225	5,000

Linear Programming

The linear programming analysis generally followed the format previously outlined *(Leak 1964)*. The yield equation or objective equation was of the form:

$$Y=\Sigma\ \Sigma\ A_{ij}\ V_{ij} + \Sigma\Sigma B_{ij}\ T_{ij}$$

in which—

Y=Total yield.
A=Area harvested (acres clearcut).
V=Volume per acre harvested (clearcut).
B=Area thinned (acres).
T=Volume per acre thinned.
i=The number of the operating cycle (1, 2, 3, etc.).
j=The age class (1, 2, 3, etc.).

Area thinned (if any) in the above equation was expressed as initial acres minus previous acres harvested, so that the final objective equation was in terms of the variables A, V, and T.

Restrictions on the acres present in the forest were expressed by equations similar to these:

$$A_{11} + A_{22} + A_{33} + A_{44} \ldots\ldots + A_{99} = \underline{\qquad\quad}\text{acres}$$

$$A_{12} + A_{23} + A_{34} + A_{45} \ldots\ldots + A_{89} = \underline{\qquad\quad}\text{acres}$$

Restrictions of equal-acreage cuts per operating cycle were applied to ensure the buildup of a balanced age-class distribution. And no harvest cutting was allowed in new stands created during the adjustment period. Equations were of the form:

$$A_{11} + A_{12} + A_{13} \ldots + A_{19} - A_{22} - A_{23} - A_{24} \ldots - A_{29} = 0$$

The linear programming analyses were run on an IBM 360 computer, using a specially written program. Programming and analytical methods are available upon request to the authors. The output of each analysis consisted of the acres to harvest and thin by age classes and operating cycles for a given management situation so as to maximize the yield equation—the total yield over the first rotation period.

RESULTS

Cutting Strategies

Optimum cutting strategies are shown in the appendix for both managed and unmanaged treatments of situations I (tables 7 and 8), II (tables 9 and 10), III (tables 11 and 12), and IV (tables 13 and 14). These cutting strategies show the percent of total forest area to clearcut by stand age-class and operating cycle so as to (1) maximize board-foot production over the first rotation, (2) build up a balanced distribution of age classes by the end of the first rotation, and (3) keep within the acreage limitations of each forest situation.

These cutting strategies can be used as broad, guiding principles on northern hardwood forest properties with similar age-class distributions, where sustained yield and maximum volume production are of interest. The fairly long operating cycles—20 years—allow for considerable flexibility in year-to-year cutting activity, to allow for variations in markets and other local conditions.

Where age-class distributions, rotations, volume yields, and management objectives differ from those reported in this paper, appropriate cutting strategies probably can be developed by the linear programming methods that we have used.

Examination of the cutting strategies (tables 7 to 14) shows that where a backlog of old-growth exists (situations I, II, III), only a small amount of cutting should be done in stands less than 120 years old; and this small amount should be done within the first 20-year operating cycle. This indicates that, although pulpwood and small sawtimber sales might be required during the first cycle, cuts during following cycles would be concentrated in reasonably heavy sawtimber.

Under situation IV (decreasing acres by age classes and no uneven-aged backlog) the best strategy was to cut mostly in young stands up through the second or third operating cycle. And the managed situation IV required that some stands be carried over into the 140 to 160 class before harvest, one class beyond the chosen rotation age.

In most forest situations, there was a tendency toward more cutting in the younger age classes when the forest was under management. This was due primarily to the shorter rotation under management, which allowed less time, and consequently less freedom, for shifting the cutting into higher-volume stands. However, as previously noted, the degree of cutting in young stands under management appears feasible, except for situation IV; and perhaps during the first operating cycle of the other three situations. Where a strategy is found infeasible, a more acceptable cutting pattern probably can be developed by accepting lower volume yields, lengthening the rotation, or lengthening the adjustment period.

For example, in an attempt to reduce the degree of cutting in young stands, a reanalysis was made of situation I under management. This time, no clearcutting was allowed in stands less than 60 years old. The resultant strategy is shown in table 8 (figures in parentheses). The major change was an increase in the clearcutting of stands in the 60- to 100-year bracket. As shown in the next section, this new strategy resulted in only a small drop in volume yields.

Yields

By following the cutting strategies outlined in the previous section, yields generally will not vary greatly from one operating cycle to another, under both unmanaged (table 5) or managed (table 6) conditions. The only important exception to this is in situation IV (decreasing acreages by age class and no backlog of uneven-aged timber). Here, the yields during the first and second operating cycles are markedly low.

By incorporating volume yield restrictions into the linear programming analysis, it was found that, in some cases, yields could be made to follow a regular increasing progression. However, this is accomplished only with some loss in total yields.

Under management (table 6) total yields for all situations tended to be about equally divided between thinnings and harvest cuttings. However, under situations II and III, the harvest yields during the first operating cycle were proportionately low, and situation IV harvest yields were low during the first two operating cycles. During the remaining cycles, the proportion of harvest yields, which no doubt produced timber of higher quality than the intermediate cuts, was reasonably high.

The best appraisals of productivity of the various forest situations and the effects of management are made by converting the yields in tables 5 and 6 to yield per acre per year. Using a rotation age of 160 years for the unmanaged forests and 120 for the managed forests, the annual per-acre yields in board feet over the rotation are:

		Managed		
Situation	*Unmanaged*	*Intermediate*	*Harvest*	*Total*
I	82.4	96.7	102.2	198.9
II	88.6	114.4	100.3	214.7
III	82.4	83.0	103.6	186.6
IV	67.9	73.1	89.5	162.6

Those forest conditions with a higher proportion of large timber (situations I, II, and III) naturally show greater annual production rates than situation IV, which had no backlog of uneven-aged timber and a small proportion of acreage in the older age classes.

The managed forests had about 2-1/3 times the annual produc-

Table 5.—*Yields in board feet per acre of total forest land without management (clearcutting only)*

Operating cycle (years)	Management situation			
	I	II	III	IV
0 - 20	996	1,436	1,436	546
20 - 40	1,444	1,253	1,435	219
40 - 60	1,455	1,572	1,401	1,239
60 - 80	1,378	1,595	1,332	1,245
80 - 100	1,344	1,713	1,298	1,245
100 - 120	1,567	1,760	1,382	1,472
120 - 140	1,689	1,728	1,571	1,568
140 - 160	1,755	1,616	1,577	1,568
160 - 180	1,556	1,506	1,760	1,757
All	13,184	14,179	13,192	10,859

Table 6.—*Yields in board feet per acre of total forest land under management by management situation*

Operating cycle (years)	I			II			III			IV		
	Inter-mediate cutting	Harvest cutting	Total	Inter-mediate cutting	Harvest cutting	Total	Inter-mediate cutting	Harvest cutting	Total	Inter-mediate cutting	Harvest cutting	Total
0 - 20	1,654	1,060	2,714	2,297	892	3,189	1,565	403	1,968	636	17	653
20 - 40	1,639	1,815	3,454	2,396	1,597	3,993	1,312	1,838	3,150	1,104	442	1,546
40 - 60	1,849	1,654	3,503	2,302	1,820	4,122	1,273	1,843	3,116	1,219	1,893	3,112
60 - 80	1,740	1,690	3,430	1,948	1,928	3,876	1,360	1,909	3,269	1,364	1,932	3,296
80 - 100	1,668	2,039	3,707	1,729	1,985	3,714	1,452	2,035	3,487	1,453	2,042	3,495
100 - 120	1,550	2,149	3,699	1,550	1,961	3,511	1,498	2,150	3,648	1,498	2,152	3,650
120 - 140	1,500	1,858	3,358	1,500	1,856	3,356	1,497	2,259	3,756	1,496	2,261	3,757
All	11,600	12,265	23,865	13,722	12,039	25,761	9,957	12,437	22,394	8,770	10,739	19,509

tion rates of the unmanaged forests. Harvest yields under management were roughly 1¼ times greater than corresponding unmanaged yields; this difference reflects the shorter rotation possible with regular thinnings. However, the major effect of thinning upon total yields was the contribution of substantial intermediate yields, and a reduction in rotation lengths.

Under the revised strategy for situation I, where no clearcutting was allowed in stands less than 60 years old (table 8, figures in parentheses), total volume yields were reduced from 198.9 board feet per acre per year, to a little more than 197 board feet—a reduction of less than 1 percent. If clearcutting (or its equivalent, such as broadcast chemical liberation) of young stands up to 60 years old is not feasible, the revised strategy appears to be a good alternative.

DISCUSSION

The cutting strategies presented here are intended as examples of long-term guides—not inflexible rules—to the regulation of northern hardwood forests over the first rotation. These cutting strategies will maximize estimated board-foot production for the four situations examined, and produce a balanced even-aged forest by the end of the first rotation. Where forest conditions and management objectives are similar to those in this study, these cutting strategies might be used directly as broad guiding principles. However, in most cases, the strategy to be used on a given forest property should be based on an analysis of the type described in this paper, using local conditions and management policies.

In either case, the adoption of an appropriate cutting strategy must be followed by the development of a short-term (5 to 10 years, for example) cutting plan listing the areas to be marked, sold, and cut during the planning period. Toward the end of this period, it would be wise to develop another cutting strategy, incorporating any changes in forest conditions and management objectives.

Under the management situations investigated in this study, yields per acre per year for the first rotation in the managed forests were about 2-1/3 times those yields in the unmanaged forests. A portion of this difference was attributed to increased board-foot growth rates after thinning. However, the major factor was the intermediate yields from commercial thinning. Under operating cycles shorter than 20 years, total yields under management could no doubt be increased.

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Table 7.—*Situation I: unmanaged (clearcutting only) cutting strategy required to maximize production, by percent of total forest area to harvest*

Operating cycle (years)	Stand age class in years										
	0-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	160-180	Uneven-aged	All
0 - 20	—	—	—	—	3.44	3.06	2.00	—	—	2.61	11.11
20 - 40	—	—	—	—	—	—	—	—	—	11.11	11.11
40 - 60	—	—	—	—	—	—	—	0.94	—	10.17	11.11
60 - 80	—	—	—	—	—	—	6.56	4.56	—	—	11.12
80 - 100	—	—	—	—	—	—	7.67	3.44	—	—	11.11
100 - 120	—	—	—	—	—	—	—	11.11	—	—	11.11
120 - 140	—	—	—	—	—	—	—	3.89	7.22	—	11.11
140 - 160	—	—	—	—	—	—	—	—	11.11	—	11.11
160 - 180	—	—	—	—	—	—	—	—	4.00	7.11	11.11

Table 8.—*Situation I: managed cutting strategy required to maximize production by percent of total forest area to clearcut (unharvested areas will be thinned or partially cut).*

Figures in parentheses are the best cutting strategy when no clearcutting is allowed in stands younger than 60 years old

Operating cycle (years)	Stand age class in years								
	0-20	20-40	40-60	60-80	80-100	100-120	120-140	Uneven-aged	All
0 - 20	4.00	0.71	1.14	—	—	—	2.00	6.43	14.28
	—	—	—	—	—	—	(2.00)	(12.28)	(14.28)
20 - 40	—	—	—	—	—	—	4.00	10.28	14.28
	—	—	—	(1.86)	—	—	(4.00)	(8.43)	(14.29)
40 - 60	—	—	—	—	—	6.29	8.00	—	14.29
	—	—	—	(.71)	(5.57)	—	(8.00)	—	(14.28)
60 - 80	—	—	—	—	—	10.57	3.71	—	14.28
	—	—	—	—	—	(4.29)	(10.00)	—	(14.29)
80 - 100	—	—	—	—	—	—	14.29	—	14.29
	—	—	—	—	—	—	(14.28)	—	(14.28)
100 - 120	—	—	—	—	—	—	14.29	—	14.29
	—	—	—	—	—	—	(14.29)	—	(14.29)
120 - 140	—	—	—	—	—	—	—	14.29	14.29
	—	—	—	—	—	—	(4.00)	(10.29)	(14.29)

Table 9.—*Situation II: unmanaged (clearcutting only) cutting strategy required to maximize production, by percent of total forest area to harvest*

Operating cycle (years)	Stand age class in years										
	0-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	160-180	Uneven-aged	All
0 - 20	—	—	—	—	—	—	—	—	—	11.05	11.05
20 - 40	—	—	—	—	—	—	9.42	—	—	1.52	10.94
40 - 60	—	—	—	—	—	—	—	11.15	—	—	11.15
60 - 80	—	—	—	—	—	—	—	9.71	1.43	—	11.14
80 - 100	—	—	—	—	—	—	—	2.86	8.29	—	11.15
100 - 120	—	—	—	—	—	—	—	—	11.14	—	11.14
120 - 140	—	—	—	—	—	—	—	—	10.00	1.14	11.14
140 - 160	—	—	—	—	—	—	—	—	6.00	5.14	11.14
160 - 180	—	—	—	—	—	—	—	—	2.00	9.15	11.15

Table 10.—*Situation II: managed cutting strategy required to maximize production, by percent of total forest area to clearcut (unharvested areas will be thinned or partially cut)*

Operating cycle (years)	Stand age class in years								
	0-20	20-40	40-60	60-80	80-100	100-120	120-140	Uneven-aged	All
0 - 20	2.00	0.86	—	—	—	11.43	—	—	14.29
20 - 40	—	—	—	—	—	3.71	10.57	—	14.28
40 - 60	—	—	—	—	—	—	14.29	—	14.29
60 - 80	—	—	—	—	—	—	14.00	0.29	14.29
80 - 100	—	—	—	—	—	—	10.00	4.29	14.29
100 - 120	—	—	—	—	—	—	5.14	9.14	14.28
120 - 140	—	—	—	—	—	—	—	14.28	14.28

Table 11.—*Situation III: unmanaged (clearcutting only) cutting strategy required to maximize production, by percent of total forest area to harvest*

Operating cycle (years)	Stand age class in years										
	0-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	160-180	Uneven-aged	All
0 - 20	—	—	—	—	—	—	—	—	—	11.05	11.05
20 - 40	—	—	—	—	—	—	—	—	—	11.04	11.04
40 - 60	—	—	—	—	—	—	3.13	2.00	—	5.91	11.04
60 - 80	—	—	—	—	—	—	8.28	2.87	—	—	11.15
80 - 100	—	—	—	—	—	—	9.42	1.72	—	—	11.14
100 - 120	—	—	—	—	—	—	6.57	4.58	—	—	11.15
120 - 140	—	—	—	—	—	—	—	11.14	—	—	11.14
140 - 160	—	—	—	—	—	—	—	10.86	0.29	—	11.15
160 - 180	—	—	—	—	—	—	—	—	11.14	—	11.14

Table 12.—*Situation III: managed cutting strategy required to maximize production, by percent of total forest area to clearcut (unharvested areas will be thinned or partially cut)*

Operating cycle (years)	Stand age class in years								
	0-20	20-40	40-60	60-80	80-100	100-120	120-140	Uneven-aged	All
0 - 20	7.70	3.40	—	—	—	—	—	3.10	14.20
20 - 40	—	—	—	—	—	—	2.00	12.30	14.30
40 - 60	—	—	—	—	—	—	6.00	8.30	14.30
60 - 80	—	—	—	—	—	—	10.00	4.30	14.30
80 - 100	—	—	—	—	—	0.30	14.00	—	14.30
100 - 120	—	—	—	—	—	—	14.30	—	14.30
120 - 140	—	—	—	—	—	—	14.30	—	14.30

Table 13.—*Situation IV: unmanaged (clearcutting only) cutting strategy required to maximize production, by percent of total forest area to harvest*

Operating cycle (years)	Stand age class in years									
	0-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	160-180	All
0 - 20	3.76	0.27	—	—	—	7.00	—	—	—	11.03
20 - 40	—	—	7.24	—	3.88	—	—	—	—	11.12
40 - 60	—	—	—	—	.12	—	11.00	—	—	11.12
60 - 80	—	—	—	—	—	—	11.12	—	—	11.12
80 - 100	—	—	—	—	—	—	11.12	—	—	11.12
100 - 120	—	—	—	—	—	—	3.37	7.76	—	11.13
120 - 140	—	—	—	—	—	—	—	11.12	—	11.12
140 - 160	—	—	—	—	—	—	—	11.12	—	11.12
160 - 180	—	—	—	—	—	—	—	—	11.12	11.12

Table 14.—*Situation IV: managed cutting strategy required to maximize production, by percent of total forest area to clearcut (unharvested areas will be thinned or partially cut)*

Operating cycle (years)	Stand age class in years								
	0-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	All
0 - 20	1.16	7.69	4.69	0.69	—	—	—	—	14.23
20 - 40	—	10.53	—	—	—	—	3.69	—	14.22
40 - 60	—	—	—	—	—	—	11.00	3.31	14.31
60 - 80	—	—	—	—	—	—	14.31	—	14.31
80 - 100	—	—	—	—	—	—	14.31	—	14.31
100 - 120	—	—	—	—	—	—	14.31	—	14.31
120 - 140	—	—	—	—	—	—	14.31	—	14.31

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20 Years of INTENSIVE UNEVEN-AGED MANAGEMENT

: Effect on Growth, Yield, and Species Composition in Two Hardwood Stands in West Virginia

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RESULTS AFTER 20 YEARS

IN 1948 A STUDY of uneven-aged forest management, with individual tree-selection cuttings, was begun on two 31-acre stands of Appalachian hardwoods in West Virginia. Now, after 20 years, these stands are beginning to show how this kind of management affects growth, yield, and species composition.

The stands are located on the Fernow Experimental Forest near Parsons, West Virginia, one of the outdoor laboratories of the Northeastern Forest Experiment Station, USDA Forest Service. Elevation is about 2,600 feet. Average rainfall is about 59 inches. Soils are well-drained, of medium texture, and 3 to 4 feet deep.

Both stands had been first cut for sawlogs about 40 years before the study was begun. In that cutting, defective trees, below sawlog-size stems, and unmerchantable species were left. So the 1948 stand was made up of two distinct groups of trees: the old growth left from the original logging, and the second growth that came in afterward.

Both areas have average site indexes (for oak) of 75 feet (*Trimble and Weitzman 1956*). Both areas have sites ranging from dry ridge tops to moist stream bottoms; both were fairly typical in 1948 of stand conditions in the northern Appalachian region, though they represented two different stages in the recovery of cut-over, burned-over forest land. Cutting was followed by fire on both areas, but stand 1 appeared to have suffered more severely, possibly because it was closer to an old logging railroad. The stand in 1948 still reflected this past damage.

The results of the first 10 years of this study have been published as an economic analysis *(Mitchell and Webster 1961)*. This report deals with the effects of one type of management (and of the maturation of the stand) over a 20-year period. And from this record, predictions can be made about the future developments of the two areas.

METHODS

A 100-percent inventory was made of each stand in 1948. Inventories were repeated in 1958 and 1968. All trees over 5.0 inches d.b.h. were tallied by 2-inch d.b.h. (diameter breast high) classes. Local volume tables were made as a basis for estimating board-foot and cubic-foot volumes. Board feet were computed according to the International ¼-inch kerf rule for trees over 11.0 inches d.b.h. to an 8-inch top i.b. (inside bark). Cubic-foot volumes were computed for trees over 5.0 inches d.b.h. to a 4-inch top i.b.

Log grade in sawtimber-size trees was sampled, using the grades developed by the USDA Forest Service, Forest Products Laboratory, and following the definitions published by Ostrander and others *(1965)*.

RESULTS

Harvest Cuttings

For the first 10 years of the study, a cutting was made annually in some part of each stand, as a farmer might cut his woodlot. During the second 10 years, cuttings were made every 2 years in each stand. All together 15 cuttings were made in each area. All cut volumes used in this report are based on marked-tree tallies.

Most of the cuttings produced only sawtimber; some produced only pulpwood; a few produced both sawlogs and pulpwood. Over the 20-year period, stand 1 produced a harvest of 2.4 thousand board feet of sawlogs per acre and 190 cubic feet (inside bark), or 2.7 cords (at 70 cubic feet per cord) of pulpwood per acre (table 1). Stand 2 produced 5.2 thousand board feet of sawlogs per acre and 104 cubic feet or 1.5 cords of pulpwood per acre. Pulpwood came mostly from trees in the 5- to 11-inch d.b.h. range; tops and limbs of harvested sawtimber trees were utilized to only a slight extent.

The cutting was heavier during the first 10 years, when emphasis was placed on cleaning up the stand as rapidly as possible.

Table 1.—*Material harvested per acre*

Stand number	Board feet[1]			Cords[2]		
	1949-58	1959-68	Total	1949-58	1959-68	Total
1	2,000	430	2,430	1.54	1.18	2.72
2	3,750	1,420	5,170	1.07	.40	1.47

[1] International ¼-inch kerf rule, to an 8-inch top i.b. in trees over 11.0 inches d.b.h.

[2] At 70 cubic feet per cord, computed to a 4-inch top i.b. in trees 5- to 11-inches d.b.h. If cubic feet had been computed outside bark, 80 cubic feet per cord would have been used.

During this period, most of the old-growth trees were cut. During the second 10 years, the cutting was lighter, since the main effort was directed toward building up the stocking.

Growth

Growth data were computed for the two 10-year periods, then combined for the 20-year record (table 2). Only merchantable trees were used; most cull trees were killed during the first year of the study. Growth figures include the cuttings as well as changes in the stand. Stand ingrowth is included; mortality is excluded.

Board-foot growth, computed for the period for trees over 11.0 inches d.b.h., averaged 256 feet per year for stand 1, and 361 feet for stand 2. Annual *cubic-foot* growth was computed for all trees over 5.0 inches d.b.h. For stand 1 it averaged 48 cubic feet and for stand 2 it averaged 62 cubic feet. Annual *basal-area* growth was 2.08 square feet for stand 1 and 2.28 square feet for stand 2.

Ingrowth accounted for a high percentage of board-foot growth over the 20-year period; 45 percent for stand 1 and 32 percent for stand 2 (table 2). For cubic-foot growth the percentage of ingrowth was lower: 8 percent for each stand. For both stands, and for both board-foot and cubic-foot growth, ingrowth percentage was higher in the first 10-year period than in the second.

Table 2.—*Periodic annual growth rates per acre*

Item	Board-foot growth[1]			Cubic-foot growth[2]			Basal-area growth[3]		
	1949-58	1959-68	Average	1949-58	1959-68	Average	1949-58	1959-68	Average
Stand 1:									
Net growth	228	284	256	48.6	48.0	48.3	2.16	2.00	2.08
Percent ingrowth	50	40	45	11	4	8	—	—	—
Stand 2:									
Net growth	402	319	361	69.4	54.1	61.8	2.57	2.00	2.28
Percent ingrowth	36	28	32	8	7	8	—	—	—
Average									
Net growth	315	302	308	59.0	51.0	55.0	2.36	2.00	2.18
Percent ingrowth	43	34	39	10	6	8	—	—	—

[1] International ¼-inch kerf rule, to an 8-inch top i.b. in trees over 11.0 inches d.b.h.

[2] In trees over 5.0 inches d.b.h., to a 4-inch top i.b.

[3] For trees over 5.0 inches d.b.h.

Sawtimber Quality

Timber quality was measured by a combination of three yardsticks: (1) the volume of the cull trees in the stand, (2) defective material in merchantable trees, and (3) the grade of the logs in merchantable trees. A cull sawtimber tree was defined as a tree over 11.0 inches d.b.h., which does not contain at least one 16-foot log having 50 percent or more merchantable volume.

Total inventories gave us the volume in cull trees; scaling records in these and similarly treated stands provided an estimate of volume reduction due to scaling defects; and sample tree grading during the inventories yielded an estimate of log grade in the sawtimber stand.

Over the 20 years, in stand 1 volume per acre in cull trees dropped from 746 board feet to 68, a reduction from 14 percent to less than 1 percent (table 3). In stand 2, the reduction was from 1,353 to 42 board feet, or from 13 percent to less than ½ percent of sawtimber volume.

A study made in these and other similar stands showed that after repeated selection cutting we can expect scaling deductions on merchantable trees to drop below 5 percent of sawtimber volume *(Trimble 1965a)*. These deductions include cull logs in merchantable trees, and crook, sweep, shake, and rot in merchantable logs.

Factory log grades 1 and 2 are the money makers. Twenty years of management—and of increasing stand diameter—have raised the percentage of merchantable sawtimber volume in the stand in these two grade classes from 19.2 to 51.4 for stand 1 and from 29.7 to 58.9 for stand 2 (table 4).

Table 3.—*Per-acre volumes, merchantable and cull*

Stand number	1948				1968			
	Merch. volume	Cull tree volume	Total volume	In cull trees	Merch. volume	Cull tree volume	Total volume	In cull trees
	Bd. ft.	*Bd. ft.*	*Bd. ft.*	*Pct.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Pct.*
1	4,611	746	5,357	13.9	7,296	68	7,364	0.9
2	9,227	1,353	10,580	12.8	11,274	42	11,316	0.4

Table 4.—*Percentage of sawtimber volume, by log grades*

Date	Log grade 1	Log grade 2	Log grade 3	Log grades 4 and 5	Log grade 6 (cull log)
		STAND 1			
1948	11.0	8.2	52.7	23.3	4.8
1958	11.7	14.9	39.6	32.1	1.7
1968	27.1	24.3	39.6	8.3	0.7
		STAND 2			
1948	10.7	19.0	38.0	26.8	5.5
1958	25.8	21.1	38.8	13.4	0.9
1968	35.6	23.3	33.9	6.9	0.3

Species Composition

Typical of Appalachian hardwood stands, both stands are composed of a great number of species. In 1948, 21 commercial species grew in stand 1 and 24 grew in stand 2. Many of these occurred so infrequently or were of such low value that they were of little economic importance. During the 20-year period there was little change in the total number of species, but their relative frequency in the stand changed appreciably (table 5).

From previous work in this area we expected that, on these sites, uneven-aged management with selection cutting would result in an increase of shade-tolerant species such as the maples and beech *(Trimble 1965b).* These species reproduce and the seedlings can develop under the canopy conditions produced by uneven-aged management. Typically this trend would be accompanied by the diminution of such shade intolerants as black cherry and yellow-poplar. These species cannot thrive under canopy.

These expectations were borne out by the record. In 1948, beech, red maple and sugar maple made up 13.5 percent of the 5- to 11-inch stems in stand 1 and 16.6 percent in stand 2. In 1968, the percentages had increased to 25.3 and 32.3. Meanwhile, yellow-poplar and black cherry, which in 1948 made up 15.1 percent of the 5- to 11-inch stems in stand 1 and 21.8 percent in stand 2 dropped to 8.8 and 6.1 percent. Most of the 5- to 11-inch stems had grown into the sawtimber size class after 20 years,

Table 5.—*Species composition, twelve most numerous species*

	5- to 11-inch trees				Trees over 11 inches			
	1948		1968		1948		1968	
	Species in numerical order	Percent of total stand	Species in numerical order	Percent of total stand	Species in numerical order	Percent of total stand	Species in numerical order	Percent of total stand
				STAND 1				
1.	Red oak	18.3	Sweet birch	20.6	Beech	22.8	Red oak	36.0
2.	Sweet birch	17.6	Red oak	13.0	Red oak	21.2	Yellow-poplar	23.8
3.	Yellow-poplar	12.1	Red maple	11.0	Yellow-poplar	17.8	Beech	6.0
4.	Black locust	6.6	Beech	9.4	Black cherry	6.6	Chestnut oak	5.8
5.	Red maple	6.6	Yellow-poplar	7.2	Sugar maple	5.3	Black cherry	5.4
6.	Beech	5.2	Fraser magnolia	5.7	Sweet birch	4.1	Red maple	4.2
7.	Sassafras	5.1	Cucumbertree	5.5	Chestnut oak	4.1	Sweet birch	3.5
8.	Cucumbertree	4.6	Sugar maple	4.9	Black gum	4.1	Cucumbertree	3.1
9.	Chestnut oak	4.1	Chestnut oak	4.7	Red maple	3.4	Fraser magnolia	2.5
10.	Black cherry	3.0	Black locust	3.0	Cucumbertree	2.2	Sugar maple	1.9
11.	White ash	2.4	Serviceberry	2.6	Hickory	1.9	Basswood	1.7
12.	Sugar maple	1.7	White ash	2.4	Basswood	1.2	White ash	1.7
	Sum of 12	87.3		90.0		94.7		95.6
				STAND 2				
1.	Yellow-poplar	18.0	Sweet birch	13.0	Yellow-poplar	23.3	Yellow-poplar	31.2
2.	Red oak	12.9	Red maple	12.5	Beech	12.6	Red oak	20.0
3.	Sweet birch	8.4	Sugar maple	10.9	Red oak	11.4	Basswood	8.8
4.	Beech	8.0	Sassafras	9.8	Sugar maple	7.7	Beech	6.7
5.	Basswood	7.6	Red oak	9.1	Basswood	7.2	Black cherry	5.7
6.	Red maple	6.1	Beech	8.9	Sweet birch	6.3	Chestnut oak	4.5
7.	Sassafras	5.6	Basswood	6.4	Black cherry	6.0	Hickory	3.5
8.	Yellow-poplar	4.4	Yellow birch	5.9	Chestnut oak	5.1	Sugar maple	2.9
9.	Black cherry	3.8	Yellow-poplar	4.9	Hickory	4.0	Red maple	2.9
10.	White ash	3.2	Fraser magnolia	3.5	White oak	3.7	White ash	2.5
11.	Cucumbertree	3.1	Cucumbertree	3.1	Black locust	2.3	White oak	2.4
12.	Black locust	2.9	Hickory	2.7	Yellow birch	2.3	Sweet birch	2.2
	Sum of 12	8.40		90.7		91.9		93.3

and there were few, if any, replacements. On both areas in 1968 sweet birch became the most numerous species in the 5- to 11-inch stand. The undesirable Fraser magnolia was not represented in the 5- to 11-inch stand in 1948, but 20 years later it made up 6.6 and 3.2 percent of the small stems in stands 1 and 2. This increase was the result of vigorous stump sprouting by this species.

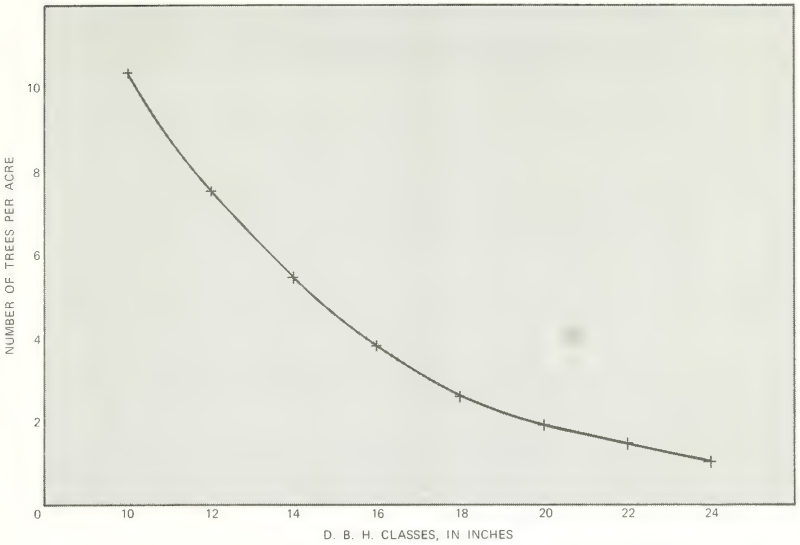
The effect of the silvicultural system has not in 20 years greatly affected the composition of the stand now over 11.0 inches d.b.h. These trees came in after a clearcutting 60 to 65 years ago. It will be another 20 years or so before the species composition of the sawtimber stand strongly reflects the current program of periodic individual tree-selection cuttings. However, one definite effect of management to date is the decline of beech sawtimber. Because of its typically poor quality, it has been marked heavily for removal. Sugar maple sawtimber was also heavily marked during the 20-year period because most of it was old growth.

Diameter Distribution

In a stand managed under the uneven-aged system, one of the goals is to harvest approximately equal volumes in more-or-less equally spaced cuttings. This requires that a fairly consistent diameter distribution be maintained. It requires also that this distribution be so balanced that sufficient numbers of trees grow into the higher d.b.h. classes.

De Liocourt devised a method that has been used to accomplish this objective, and it is described by Meyer et al. *(1961)*. A. "Q", or proportional relationship between number of trees in different diameter classes, defines an inverse J-shaped curve (fig. 1). For example, using a Q of 1.4 with 2-inch diameter classes means that the stand should contain 1.4 times as many trees in each decreasing d.b.h. class; that is, the 16-inch class should have 1.4 times as many trees as the 18-inch class, etc. In actual practice —marking a stand to leave a given Q—the diameter classes are usually combined into 4- to 6-inch classes. Determination of stand-structure guides involves not only picking a suitable Q, but also deciding what basal area to leave and the maximum-size tree to leave.

Figure 1.—J-shaped curve illustrating a "Q" of 1.4.



The average Q's for the two stands in 1948 and 1968 were as follows:

	Computed Q	
Stand	*1948*	*1968*
1	1.9	1.7
2	1.5	1.5

During the 20 years of management, tree size has increased, as indicated by the increasing number of stems in the sawtimber-size d.b.h. classes (table 6). Average d.b.h., including all sound stems over 5.0 inches d.b.h., has increased as follows:

	Average d.b.h., by years		
Stand	*1948 (inches)*	*1958 (inches)*	*1968 (inches)*
1	8.5	8.8	9.7
2	9.9	10.1	10.3

Table 6.—*Number of living trees per acre, by 2-inch d.b.h. classes*

D.b.h. class (inches)	Stand 1			Stand 2			Planned residual stand of the future[1]
	Before first cut, 1948	Cut or killed 1948-68	Trees after last cut, 1968	Before first cut, 1948	Cut or killed 1948-68	Trees after last cut, 1968	
6	86.0	27.2	50.6	49.8	10.2	48.2	26.6
8	51.0	12.0	37.4	31.5	7.1	28.0	19.0
10	28.2	6.0	27.6	23.4	5.8	17.0	13.6
12	15.8	4.5	21.0	16.2	5.2	14.6	9.7
14	8.4	3.6	13.9	11.3	4.9	12.1	6.9
16	4.0	2.7	8.6	7.1	3.4	9.0	4.9
18	2.8	1.8	4.6	5.1	3.3	6.0	3.5
20	2.2	2.0	2.0	3.1	2.0	3.8	2.5
22	1.1	1.0	1.1	2.2	1.4	2.4	1.8
24	.6	.2	.4	1.5	1.4	1.3	1.3
26	.3	.2	.3	.8	.7	.7	.9
28	.1	.1	.2	.4	.4	.3	—
30	.03	.1	.06	.2	.4	.4	—
32	—	—	—	.1	.2	—	—
34	—	—	—	.03	.06	.1	—
36	.03	.03	—	.06	.06	—	—
38	—	—	—	.03	.03	—	—
Total	200.6	61.4	167.8	152.8	46.6	143.9	90.7

[1] Goal of management is based on: Maximum size tree = 26 inches d.b.h.; Q = 1.4; basal area in trees over 5.0 inches d.b.h. = 65 square feet.

DISCUSSION & CONCLUSIONS

Twenty years of record, although detailed, is far from a satisfactory predictive base from which to postulate on the detailed behavior of these and similar stands when they fully reflect the silvicultural system practiced. However, considering the over-all lack of stand data from long-term studies, and in view of the fact that the results of this study parallel findings from other large-area studies on the Fernow Experimental Forest, we feel that certain conclusions about long-range implications are warranted.

We feel that a growth rate of 300 board feet per acre can be maintained in stands on this site quality during the period of converting to a fully managed uneven-aged condition. In cubic volume of wood, exclusive of bark, the stands can produce 55 to 60 feet, not including top and limb wood. When the volume in tops and limbs is included, and computations are based on volumes outside bark, we estimate annual production of about 1¼ cords per acre.

Previous studies on the Fernow indicate that this growth rate can be maintained on a wide range of residual stocking, possibly going as low as 65 square feet per acre (in trees over 5.0 inches d.b.h.) with a Q of 1.3 to 1.5 and a maximum-size leave tree of about 26 inches *(Trimble 1968)*. A residual stand tailored to such specifications would contain about 32 trees of sawtimber size and about 59 trees between 5 and 11 inches d.b.h. (table 6). This stand would contain about 6,665 board feet. This is less than either stand is now carrying.

The indicated growth rate should produce a per-acre harvest of approximately 3 thousand board feet every 10 years, plus 3 to 6 cords of pulpwood.

Indications are that the future stabilized stands will provide a sawlog cutting that will be composed about 60 percent of log grades 1 and 2.

On this site, the future stand will be composed primarily of the maples, beech, and sweet birch. Sugar maple will predominate in the sawtimber sizes, and sweet birch will possibly account for the greatest volume in the pulpwood-size stand.

It should be stressed that the species composition of a forest stand reflects the quality of the site, silvical characteristics of the species indigenous to the area, and the silvicultural system used to manage the stand. Strong interrelationships operate between these factors, particularly the second two. For example, and as described previously, shade-tolerant species such as sugar maple are favored by uneven-aged systems, in contrast to intolerant yellow-poplar, which cannot develop satisfactorily under an individual tree-selection cutting program. Species preferences of the forest manager, expressed through marking practices, may drastically alter the natural development of stand composition under any silvicultural system. While the characteristics of beech favor its development as a strong component in an uneven-aged system, it will generally be discriminated against in marking because of its undesirable characteristics such as poor log quality and slow growth, and thus will be relegated to the position of a minor stand component.

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Experimental Planting of 14 tree species on Pennsylvania's Anthracite Strip-Mine Spoils

by Miroslaw M. Czapowskyj

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FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
RICHARD D. LANE, DIRECTOR

FOREWORD

THIS IS THE FOURTH in a series of reports dealing with mine-spoil revegetation research in the Anthracite Region of Pennsylvania. The preceding reports were: *A guide for screen and cover planting of trees on anthracite mine-spoil areas* (USDA Forest Serv. Res. Paper NE-22, 1964); *Survival and early growth of planted forest trees on strip-mine spoils in the Anthracite Region* (USDA Forest Serv. Res. Paper NE-46, 1966); and *Response of crownvetch planted on anthracite breaker refuse* (USDA Forest Serv. Res. Note NE-78, 1968).

The Pennsylvania Power and Light Company, whose interest led to the initiation of this project on anthracite mine-spoil revegetation in 1961, financed most of the research in these reports and is continuing its support for studies in progress. The author gratefully acknowledges the cooperation and assistance of the Pennsylvania Department of Forests and Waters for supplying nursery stock, and Stephen Postupack and Joseph Paddock, contract planters, for their contributions during the planting stage of this study.

The author acknowledges William E. McQuilkin's help in preparing portions of this report.

Experimental Planting of 14 tree species on Pennsylvania's Anthracite Strip-Mine Spoils

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The Author

MIROSLAW M. CZAPOWSKYJ received a Diplomforstwirt degree from Ludwig-Maximilians University, Munich, Germany in 1949. From 1949 to 1951 he was on the staff of Wuerttemberg's Hofkammerforstamt in Altshausen, Germany. A native of the Ukraine, he has been in this country since 1951 and an American citizen since 1957. He obtained a master's degree in forestry from the University of Maine in 1958 and a Ph.D. degree in soils from Rutgers University in 1962. He joined the Northeastern Forest Experiment Station in 1961 as a research forester, and has been assigned since that time to the Station's research unit at Kingston, Pa.

A DESIGNED PLANTING EXPERIMENT

IN 1961 THE Northeastern Forest Experiment Station, in cooperation with the Pennsylvania Power and Light Company, began a research program on revegetation—primarily reforestation—of the coal-mine spoils of Pennsylvania's Anthracite Region. The first two studies were of survey type. Frank (*1964*) classified and mapped all the area disturbed by anthracite mining, which he found in 1962 to total 112,000 acres. Of this acreage, 76 percent was due to strip-mining; and more than half of the disturbed land was still practically devoid of tree cover. Czapowskyj and McQuilkin (*1966*) reported on a 1962 survey of all tree plantings made on anthracite spoils up to and including 1955 (plantings 7 or more years old). They also offered a tentative classification of anthracite strip-mine spoils as media for tree growth.

Because those early tree-planting efforts were small trials made without benefit of formal experimental design, the results were no more than indicative of survival and growth that might be expected from the various species. Therefore, in 1963 a designed planting experiment, involving 11 coniferous and 3 hardwood species, was established across a broad spectrum of strip-mine spoil types and grading conditions.

This paper presents the 5-year results from those plantings.

THE STUDY

Four strip-mine spoil types representing those described earlier (*Czapowskyj and McQuilkin 1966*) were selected as experimental planting sites. These types, designated in this paper by roman numerals I to IV, are characterized by distinct differences in the predominant parent material as follows:[1]

Type I — Black carbonaceous shale.
Type II — Gray to yellow shales.
Type III — Sandstones and conglomerates.
Type IV — Glacial till and surface deposits.

Although coal operators now are required by law (*Commonwealth of Pennsylvania 1963*) to grade the stripping spoils when mining is completed, large acreages of ungraded spoils still remain from stripping operations conducted before passage of this law. So each spoil type was represented in the experimental plantings by both graded and ungraded conditions. The spoils of the ungraded sites varied from 10 to 15 years old (since stripping) and slope angles were approximately 40°. The graded sites were 1 to 3 years old (since grading), and slope angles were mostly between 5° and 10°. All planting sites were sampled systematically to a depth of 12 inches for analysis of selected physical and chemical properties.[2]

The "soil" fraction (material passing through a 2-mm. sieve) varied considerably among the spoil types, from less than 30 percent in type I to 70 percent in type IV (appendix, table 1). Moisture retention percentages also varied. So individual spoil types and grading conditions varied considerably in their capacities to store and to supply moisture for tree survival and growth. However, under average rainfall conditions in the Anthracite Region, retention capacities are adequate for normal tree survival and growth.

Although pH values varied considerably between spoil types and grading conditions (appendix, table 2), acidity itself was not a problem. In spoil types I and III, pH values were appreciably higher in graded spoils than in ungraded spoils. The reasons for this are not clear. The lower pH values may be due partially to weathering processes, leaching of bases, and surface erosion on the ungraded spoils. On the other hand, grading of spoils exposed unweathered and unleached material.

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[1] See the appendix for a more detailed description.

[2] Chemical analysis was performed in the Soil Chemistry Laboratory of The Pennsylvania State University.

Exchangeable bases, extractable phosphorus, and total nitrogen varied from one spoil type to another and from one grading condition to another. The overall natural supply of these essential plant nutrients was low; nitrogen, in particular, was probably too low for normal tree growth. The total bases (Ca + Mg + K) in graded spoil type I, II, and III were considerably higher than in their ungraded counterparts. Ca accounted for 79 to 83 percent of the total exchangeable bases in the graded spoils as compared to 53 to 64 percent in ungraded spoils. There were no appreciable differences in chemical or physical characteristics between graded and ungraded sites on spoil-type IV.

The 14 species used in the experiment (appendix, table 3) were selected to include those that had shown the most promise in earlier mine-spoil plantings in both the Anthracite and Bituminous Regions of Pennsylvania.

The field layout consisted of 32 blocks; 8 on each spoil type, with 4 replicates each on graded and ungraded spoils. Blocks were 84 by 50 feet, with the longer dimension on the contour, thus providing for 14 rows (6 feet apart and 50 feet long) running up and down slope. In each block, 11 rows as a group were assigned to the 11 coniferous species, and 3 rows were assigned to the hardwoods. The species were randomized separately, by rows, within these groups. The conifers were planted with 2-foot spacing, or 25 trees per row; the hardwoods were planted with 3-foot spacing, or 17 trees per row. Thus, in the 32 blocks, 800 seedlings of each coniferous species and 544 seedlings (or cuttings, in the case of hybrid poplar) of each hardwood species were planted. These added up to 8,800 conifers and 1,632 hardwoods for a grand total of 10,432 seedlings and cuttings.

Planting was done by crews of experienced planters, using planting bars, during typical spring weather when spoil moisture conditions were favorable.

Survival and height growth were recorded at the end of each growing season and were summarized by species, spoil type, and grading condition. During the 5-year period, particularly in 1966 and 1967, a few blocks or parts of blocks were destroyed by renewed stripping or grading operations that were not anticipated when the sites were selected. Consequently, only limited use could be made of statistical methods for analysis of data.

RESULTS

Tree survival on graded sites was better than on ungraded sites. Overall survival was 70 percent for hardwoods and 60 percent for conifers on graded sites, compared to 40 percent for hardwoods and 32 percent for conifers on ungraded sites (fig. 1 and appendix, table 4).

The overall growth of conifers was poor to fair. Only three species—jack pine, Virginia pine, and Japanese larch—exceeded an average height of 3 feet. Growth of the hardwoods was better: average heights on graded sites ranged from 6.4 to 13.0 feet. The first three growing seasons were extremely dry, accounting for some of the mortality and retarded growth (fig. 1 and appendix, table 5).

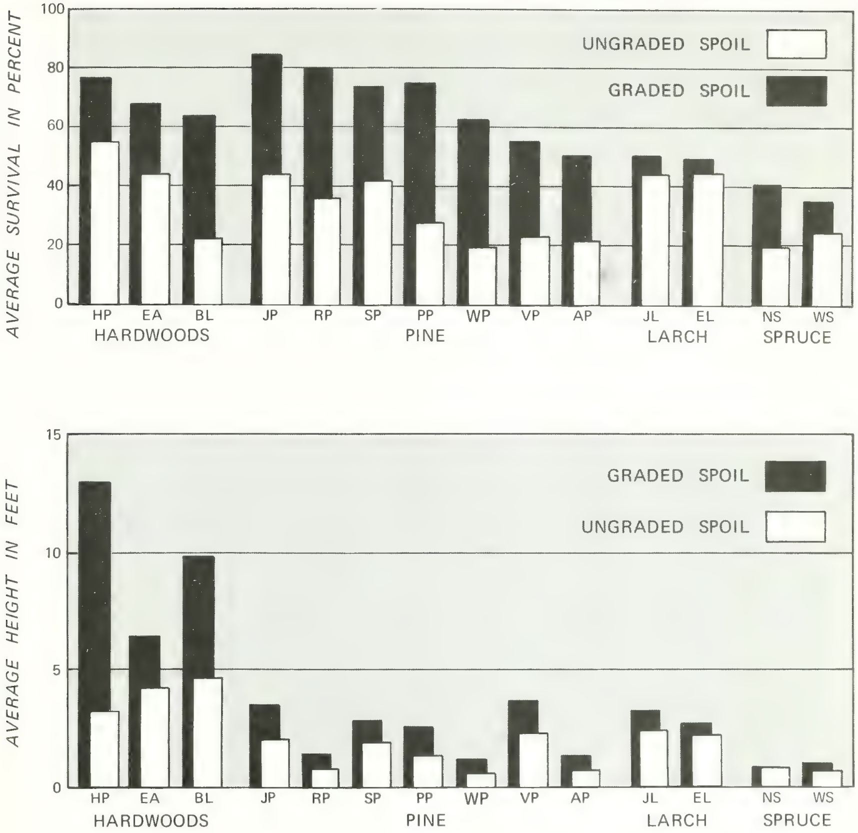
Much variation occurred between species, spoil types, and replicates. A number of instances of 90 percent or higher survival, and growth considerably better than average, were recorded.

The 5-year results in terms of survival and total height (appendix, tables 4 and 5) are discussed below in relation to the three independent variables—spoil type, grading condition, and species.

Spoil Type

The most marked spoil type effect was the poor performance on type IV (glacial till and surface deposits). This was unexpected, in view of the relatively high content of "soil"-size particles and the near neutral reaction of type IV spoil. The reason for this is not clear. However, the surface of this spoil becomes readily sealed, thus reducing rainfall infiltration, increasing water

Figure 1.—Average height and average survival of tree species 5 years after planting. (See appendix, table 3, for list of trees).



runoff, and causing intense surface erosion that resulted in tree mortality. This was not so pronounced in the other spoil types. Also, pH was possibly somewhat above the optimum for growth of essential mycorrhizal fungi and other symbiotic root organisms.

No strongly consistent differences were found among the other three spoil types. Type I usually was somewhat less favorable than types II and III, but this did not hold for all replicates and species. Because of its relatively low content of "soil"-size particles and its generally darker color, spoil-type I, and spoils like it, can be expected to be the least favorable of these three types.

Spoil types frequently vary within themselves and intergrade with each other to a degree that differences affecting plant performance are not clearly or consistently evident, at least during the early stages of growth.

The tendency of rocks to roll and slide, particularly on spoil types I and II, is another critical feature that adversely affects survival and growth. Although no attempt was made to evaluate the relative contribution of erosion and rock rolling and sliding to mortality, there is strong evidence that considerable mortality and damage was caused by rock rolling and sliding on spoil-types I and II and by erosion on spoil-types III and IV.

Erosion and rock sliding, or a combination of both, reduced tree growth by injuring and partially covering trees. Partially covered trees frequently bend, and subsequently their growth slows.

Grading Condition

The effect of grading on tree performance was much more clearly defined than the effect of spoil type. Survival on graded spoils averaged almost twice as high as on ungraded spoils. This effect was most strongly expressed on spoil-type IV, but was remarkably consistent for all species and on all spoil types (appendix, table 5). Growth was consistently better on the graded spoils, although in some instances the differences were relatively small (appendix, table 4).

These results disagree with work reported from the Central States (*Limstrom 1960; Chapman 1967*), where grading was found to have adverse effects. However, the adverse effects there were most evident on spoils derived from limestone and having a high content of clay. Such material, when graded, becomes very compact and impervious to air and water. None of the Pennsylvania anthracite spoils are of limestone origin, nor do they have such high proportions of clay. The coarser-textured anthracite spoils obviously were improved by the degree of compaction resulting from grading operations.

Besides its compaction effects, grading also improves anthracite spoils as planting sites by reducing steepness of slopes. Thus, damage from erosion and rock slidings are lessened.

Species

As expected, apart from spoil type and grading condition effects, individual species performed differently. In the following paragraphs an attempt is made to present the results, based on tables 4 and 5 (appendix) and supplemented by personal judgment, by pointing out the better (or poorer) performers and by relating their performance to site factors, planting stock used, and inherited characteristics of early growth.

Hardwoods.—The three hardwoods—hybrid poplar, black locust, and black alder—varied appreciably in their performance. Their survival and height growth appeared to be affected pri-

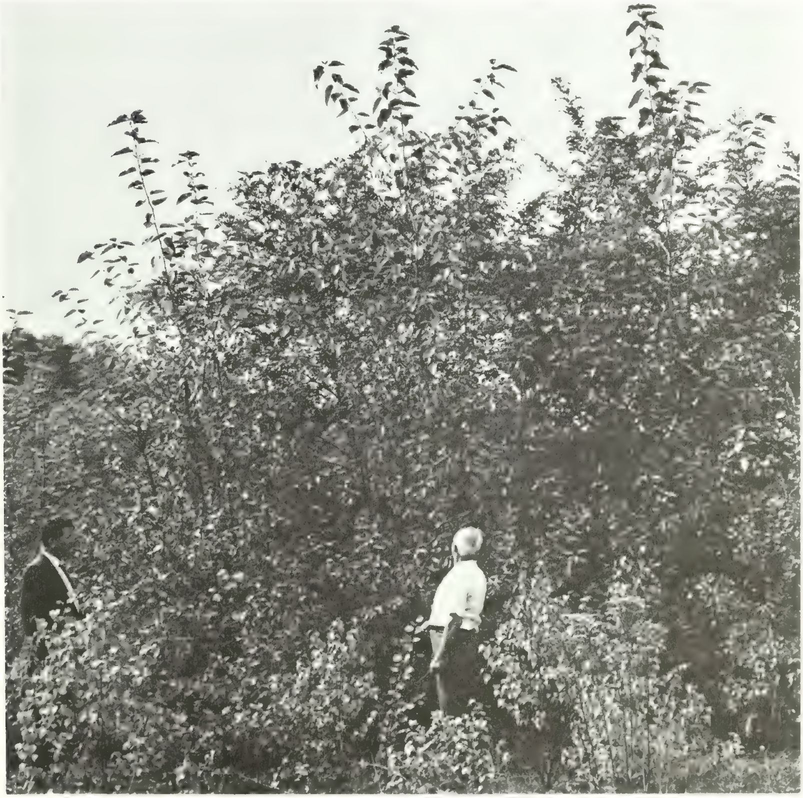


Figure 2.—Hybrid poplar NE-388 (foreground) and black locust (background) performed equally well on graded spoil-type I (sixth growing season).

marily by grading and spoil type. All three species had excellent survival and good growth on graded spoil-types I and III, and poor survival and growth, only on ungraded spoil-type IV (fig. 2). Hybrid poplar, with an overall average survival of 77 and 55 percent and a total height of 13.0 and 3.2 feet for graded and ungraded spoils respectively, performed best among the three hardwoods (fig. 3).

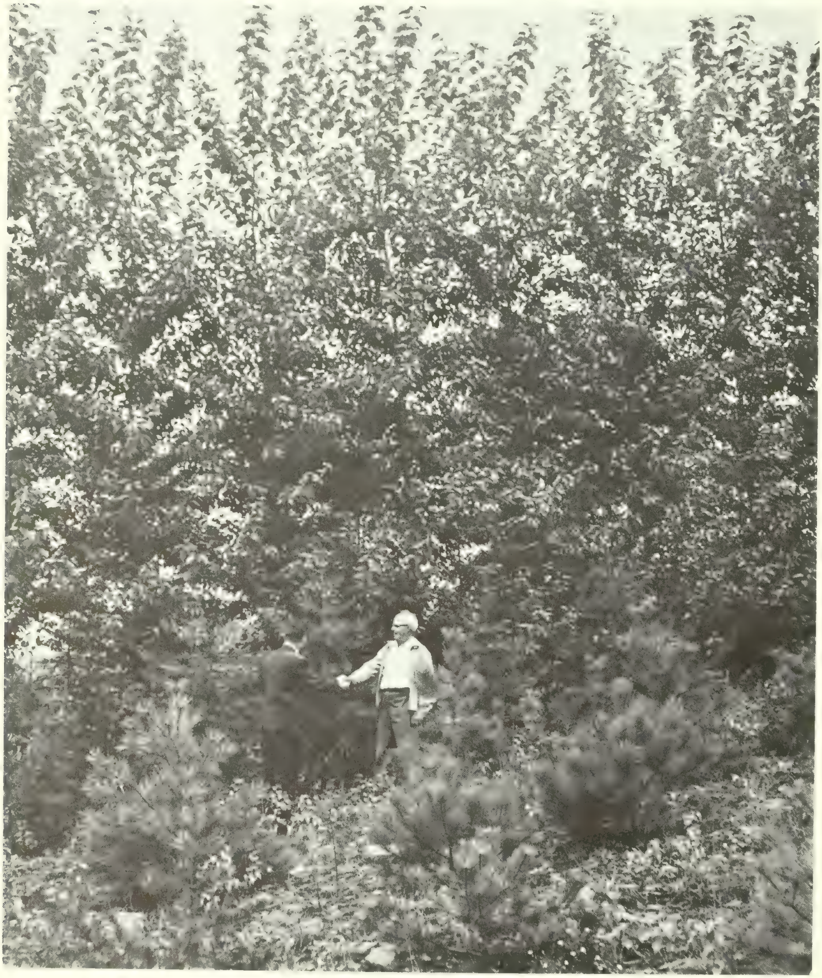


Figure 3.—Hybrid poplar NE-388 had the best height growth and survival after 5 growing seasons. Note the conifers in the foreground.

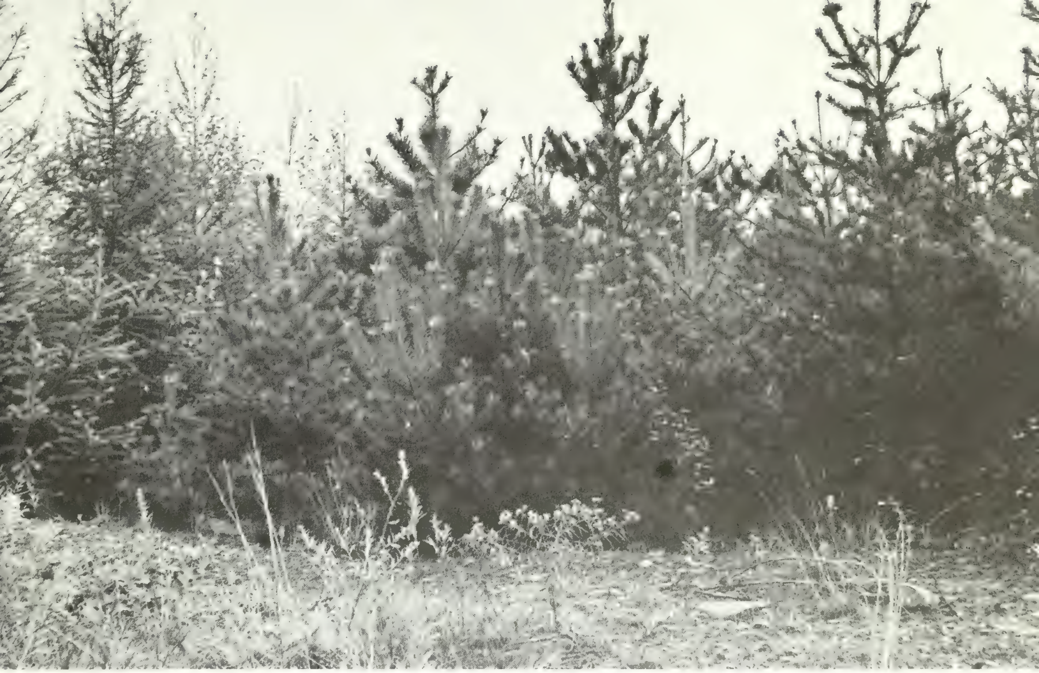


Figure 4.—Conifers planted on graded spoil-type II had excellent survival and height growth (sixth growing season).

Pines.—The performance of the seven pine species varied appreciably between grading condition and between species (fig. 4). In general, jack, red, Scotch, and pitch pines had better survival than white, Virginia, and Austrian pines. Virginia pine had the best overall height growth, followed by jack and Scotch pines. The growth of Virginia pine deserves special attention since 1-0 nursery stock was used, compared to 2-0 nursery stock used for the other pines.

Larches.—Japanese and European larches behaved similarly with respect to spoil type and grading condition. Both species survived adequately (45 to 50 percent) and grew relatively well (2.3 to 3.3 feet). There were no drastic differences in survival or height growth as in the hardwoods and pines. Their best performance was on spoil-type II, and their poorest on spoil-type IV. Average height growth of both species under all conditions was comparable to that of jack, Virginia, and Scotch pines.

Spruces.—Norway and white spruces had similar survival and growth rates, but were less successful than all other species. Adequate survival for both species was found only on graded spoil-types I and III and also, for white spruce, on ungraded spoil-type II. On the other spoil types and grading conditions, survival was poor to negligible. Average heights varied between 0.5 and 1.0 foot. Since slow growth during the early years is normal for these species at this age, this does not necessarily show whether the species is succeeding or failing. The low number of surviving trees on certain spoil types and grading conditions prohibited firm conclusions about height growth.

DISCUSSION & CONCLUSION

Results obtained in this study apply directly only to conditions under which the study was conducted. They confirm and supplement previous findings (*Mickalitis and Kutz 1949; Czapowskyj and McQuilkin 1966*) and provide new evidence that many forest plantings on anthracite strip-mine spoils can survive and grow well. Certain species may even thrive. However, one can raise many questions about the cause of variability in performance between spoil types, and graded versus ungraded conditions, and about the suitability of individual species and genera.

Since neither the causes of mortality nor spoil characteristics affecting survival and growth were studied in detail and correlated, this study does not fully explain why such differences in performance of many species were found. However, there is no doubt that the causes of variability in survival and growth lie in obscure differences, primarily in physical make-up, of the planting media.

A few factors, based on yearly survival counts and growth data[3] and on visual observations made during visits to the experimental sites, became apparent. Most mortality occurred within 2 years after planting. It also appeared evident that erosion and rock sliding and rolling were the main factors contributing to mortality and stunted growth. Because the rate of erosion is related to the soil fraction content and the slope angle, ungraded spoil-type III and, in particular, type IV are susceptible to the most severe erosion. This makes the environment for tree establishment and growth very critical on these types, especially during heavy rains.

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[3] On file at the Kingston unit of the Northeastern Forest Experiment Station, Kingston, Pa.

Further study of erosion control on these spoils warrants consideration. It was observed that the seedlings of species having reasonable height, stem diameter, and well-developed root systems had a better chance to survive. Jack, red, Scotch, and pitch pines—and occasionally Austrian pine, the larches, and hybrid poplar—apparently are superior in withstanding the adverse effects of strip-mine spoils. On the other hand, Virginia and white pines, both spruces, and, under certain conditions, even black locust had difficulty in becoming established, especially when planted on steep ungraded spoils.

Perhaps most remarkable is the strong evidence that plantings on graded sites had considerably higher survival and better height growth.

For the sake of objectivity, it should be mentioned that the year of planting, and the following two growing seasons, were extremely dry. This, without question, contributed to mortality.

These experimental plantings are too young to provide firm conclusions, especially about height growth. However, the following generalizations can be made:

- After 5 years all four anthracite strip-mine spoil types supported planted forest trees.
- The degree of performance varied from poor to excellent, depending on tree species, spoil type, and grading conditions.
- Hardwoods survived somewhat better and had much better height growth than conifers. Hybrid poplar clone NE-388 performed best.
- Jack, red, Scotch, and pitch pines showed superior survival and attained good height growth among conifers. Virginia pine was better only in height growth.

- Larches survived well under a wide range of conditions and attained good growth on ungraded sites.
- Survival of spruces was poor to adequate. Their early slow growth makes them a poor planting choice, especially on ungraded sites where erosion and rock sliding occur continuously.
- Erosion and rock sliding are prime factors of tree mortality, especially on ungraded sites. So, graded sites, regardless of spoil type, are superior tree-growth media.

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APPENDIX

Spoil Type

Anthracite strip-mine spoil types as described by M. M. Czapowskyj and W. E. McQuilkin in USDA Forest Service Research Paper NE-46, 1966.

Spoil-type I, *black carbonaceous shales.*—Coarse, black to dark grey, thin-bedded carbonaceous shales and slates, plus coal fragments. Gray to yellow thick-bedded slaty shales, sandstones, and conglomerate fragments are commonly associated.

Spoil-type II, *gray to yellow shales.*—Pale gray to yellow, soft, thick-bedded shaled and slate fragments, with black shales and sandstones frequently intermixed.

Spoil-type III, *sandstones and conglomerates.*—Gray to brown acid sandstone and conglomerate fragments. Slates and shales, together with glacial and stream deposits, often are associated. Extreme stoniness, with rocks 4 or more feet in diameter, is common.

Spoil-type VI, *glacial till and surface deposits.*—Basically glacial till and stream deposits, but sandstone, conglomerates, slates, and shale fragments may be associated. The coarse elements of the till and stream deposits vary from 2 millimeters to 2 inches in diameter.

Table 1.—*Selected physical characteristics of experimental sites (Average of eight replications)*

Spoil type	Grading condition	Coarse fraction[1]				"Soil" fraction[2]				Moisture retention		
		2-1 in.	1-½ in.	½-¼ in.	¼ in.-2mm.	Sand	Silt	Clay	Textural class	F.C.[3]	P.W.P.[4]	A.W.[5]
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*		*Percent*	*Percent*	*Percent*
I	Graded	18	21	16	16	20	6	3	sl[6]	7	2	5
	Ungraded	21	20	14	17	17	6	5	sl	10	2	8
II	Graded	11	16	16	15	27	10	5	sl	17	5	12
	Ungraded	11	15	11	15	29	10	9	sl	15	4	11
III	Graded	16	15	11	12	31	8	7	sl	8	2	6
	Ungraded	11	12	9	12	36	11	9	sl	14	3	11
IV	Graded	9	8	6	7	38	16	16	scl[7]	10	4	6
	Ungraded	8	7	7	9	40	14	15	scl	12	4	8

[1] Coarse fraction—Determined from twenty-pound samples taken from each spoil type and grading condition.

[2] "Soil" fraction—Sand, silt, and clay—Determined by the Bouyoucos hydrometer method.

[3] F. C.—Field Capacity—Based on field samples 24 hours after a heavy rain.

[4] P.W.P.—Permanent Wilting Point—15-bar moisture content of the less than 2mm. fraction and adjusted to actual field conditions.

[5] A.W.—Available Water = F.C. — P.W.P.

[6] Sandy loam

[7] Sandy clay loam

Table 2.—*Selected chemical characteristics of experimental sites (Average of eight replications)*

Spoil type	Grading conditions	Reaction	Extractable P	Total N	Exchangeable bases			Cation exchange capacity	Ca + Mg + K	
					Ca	Mg	K		Total	Saturation
		pH	*ppm*	*Pct.*	*Milliequivalents/kg of "soil" fraction*					*Pct.*
I	Graded	5.7	27.4	0.13	29.3	4.3	1.9	63.0	35.5	56
	Ungraded	4.5	59.8	.14	8.6	3.5	1.4	119.0	13.5	11
II	Graded	4.8	50.1	.07	23.4	4.1	2.2	119.3	29.7	25
	Ungraded	4.6	26.3	.15	9.0	4.8	1.7	67.0	15.3	23
III	Graded	6.3	41.9	.10	28.5	3.2	2.2	61.0	33.9	56
	Ungraded	4.2	37.7	.09	4.6	2.8	1.2	57.0	8.6	15
IV	Graded	7.1	64.2	.07	23.6	3.5	3.3	40.0	30.4	76
	Ungraded	7.5	65.6	.08	28.1	3.4	2.4	37.0	33.9	92

Table 3.—*Tree species and age of the planting stock*

Species	Age
Hybrid poplar, *P. maximowiczii* X *P. trichocarpa* NE-388	(1)
European alder, *Alnus glutinosa* (L.) Gaertn.	1-0
Black locust, *Robinia pseudoacacia* L.	1-0
Jack pine, *Pinus banksiana* Lamb.	2-0
Red pine, *Pinus resinosa* Ait.	2-0
Scotch pine, *Pinus silvestris* L.	2-0
Pitch pine, *Pinus rigida* Mill.	2-0
White pine, *Pinus strobus* L.	2-0
Virginia pine, *Pinus virginiana* Mill.	1-0
Austrian pine, *Pinus nigra* Arnold	2-0
Japanese larch, *Larix leptolepis* (Sieb. and Zucc.) Gord.	2-0
European larch, *Larix decidua* Mill.	2-0
Norway spruce, *Picea abies* (L.) Karst.	2-0
White spruce, *Picea glauca* (Moench) Voss.	2-0

[1] Cuttings

Table 4.—*Average survival—after 5 years—of forest trees planted on anthracite strip-mine spoils*

[In percent]

Species	Spoil type								Average	
	I		II		III		IV			
	G[1]	U	G	U	G	U	G	U	G	U
Hybrid poplar	90	85	78	55	97	57	42	24	77	55
European alder	88	70	69	51	85	40	31	14	68	44
Black locust	82	35	26	10	80	35	66	6	64	22
Average	87	63	58	39	87	44	46	15	70	40
Jack pine	75	46	96	84	97	33	72	13	85	44
Red pine	77	36	89	68	87	18	65	21	80	36
Scotch pine	70	32	86	88	82	38	56	12	74	42
Pitch pine	76	30	87	30	91	39	51	12	76	28
White pine	71	21	85	32	63	13	34	12	63	20
Virginia pine	62	14	64	34	59	34	38	11	56	23
Austrian pine	35	14	67	44	60	24	42	5	51	22
Japanese larch	54	65	80	74	42	27	28	12	51	44
European larch	49	54	65	70	51	50	34	5	50	45
Norway spruce	48	12	32	34	65	32	20	1	41	20
White spruce	54	15	27	52	51	28	10	4	36	25
Average	61	31	71	55	68	30	41	10	60	32

[1] G = Graded
U = Ungraded

Table 5—*Average height growth—after 5 years—of forest trees planted on anthracite strip-mine spoils*

[In feet]

Species	Spoil type								Weighted average	
	I		II		III		IV			
	G[1]	U	G	U	G	U	G	U	G	U
Hybrid poplar	14.8	3.8	7.2	1.9	19.4	2.7	4.9	5.2	13.0	3.2
European alder	6.7	5.8	5.2	.9	7.5	5.6	5.1	4.0	6.4	4.2
Black locust	12.6	6.8	6.6	2.3	10.8	3.2	6.2	5.4	9.8	4.7
Average	11.4	5.5	6.3	1.7	12.6	3.8	5.4	4.9	9.7	4.0
Jack pine	2.3	2.6	4.9	1.8	3.7	2.2	2.4	1.4	3.5	2.1
Red pine	1.3	1.0	2.0	.7	1.3	1.1	1.0	.8	1.4	.8
Scotch pine	2.5	2.4	3.6	1.6	2.5	2.4	2.6	1.6	2.8	1.9
Pitch pine	2.2	1.2	4.4	1.2	2.0	1.7	1.4	1.5	2.6	1.4
White pine	.8	.6	1.9	.5	1.1	1.1	.7	.5	1.2	.6
Virginia pine	2.9	2.0	5.2	1.9	4.0	2.8	2.0	2.2	3.7	2.3
Austrian pine	1.7	1.0	1.4	.6	1.5	.8	1.2	.8	1.4	.7
Japanese larch	3.3	2.4	3.8	2.4	3.8	2.2	1.3	2.3	3.3	2.4
European larch	3.5	2.4	2.8	2.3	2.3	2.1	1.7	1.8	2.7	2.2
Norway spruce	.9	.8	1.0	.5	.7	1.0	.8	1.0	.8	.8
White spruce	1.0	.8	1.0	.5	.9	.9	.8	.7	1.0	.7
Average	2.0	1.6	2.9	1.3	2.2	1.7	1.4	1.3	2.2	1.5

[1] G = Graded
U = Ungraded

THE FOREST SERVICE of the U. S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

An INVESTMENT GUIDE for Cooperative Forest Management in Pennsylvania

by Robert S. Manthy

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FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
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An INVESTMENT GUIDE for Cooperative Forest Management In Pennsylvania

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Introduction

ADMINISTRATORS of the Federal-State Cooperative Forest Management (CFM) program need sound investment guides for monitoring the efficiency of their program activities. This study, undertaken by the Northeastern Forest Experiment Station in cooperation with the Pennsylvania Department of Forests and Waters, provides CFM program administrators with a portion of the data they need to insure that their program and its adjunct, the Agricultural Conservation Program (ACP), are functioning in a manner that will produce maximum benefits for the dollars spent.

Nearly 76 percent of Pennsylvania's 16.7 million acres of commercial forest land is owned by 300,000 private individuals, institutions, and non-wood-using industries. In fiscal-year 1965 the Federal Government and the Commonwealth of Pennsylvania invested $264,000 in the CFM program and in ACP cost-sharing payments to assist these owners in the management of their forest lands.

Public funds are invested in CFM and the ACP as a means of encouraging Pennsylvania's private forest landowners to manage their land holdings so they will contribute more actively to current and future social welfare.

Sponsored activities are assumed to be economically sound. ACP subsidized planting, timber stand improvement, and other forestry practices are justified in terms of soil and water conservation benefits produced by these practices (*Agricultural Stabilization and Conservation Service 1963*). The assumed economic justification of CFM program activities is that the public benefits derived from the increased supply of timber, wildlife, water, and forest recreational facilities as a result of the program will equal or exceed the costs of obtaining these benefits.

But despite these assumptions, ACP and CFM administrators know relatively little about the costs and benefits of sponsored forestry practices. To estimate the relative and absolute profitability of sponsored practices, they must have detailed records of program inputs and potential outputs. On the input side, they need measurements of the actual costs of obtaining practice accomplishments. Such data are not available. And on the output side, they require measures of the increased amounts and probable worth of the timber, wildlife, water and other claimed outputs that will be available in the future as a result of current activities. Currently available measures of output are annual records of the physical size of program accomplishments.

Four types of information are provided in this report. First, the public, private, and total direct costs of undertaking all the major CFM-sponsored forestry practices in various parts of Pennsylvania are given. For those practices for which ACP subsidies are available, separate cost data are given for CFM-sponsored practices that are undertaken with and without ACP cost-sharing payments.

Second, the procedure by which cost data were collected is presented. This procedure is recommended to program administrators as an inexpensive and easily implemented means of monitoring program costs.

The third type of information makes up the major portion of this report. This is a measure of the relative and absolute profitability for timber production of the State-wide weighted average investment in tree planting and associated site preparation and fencing, and investments in hardwood timber stand improvement (TSI). Together, these practices account for virtually all the total acreage of CFM-sponsored landowner forestry-practice accomplishments in Pennsylvania. Estimates of returns are based on projected stumpage values for the maximum possible gross volume of future timber crops produced by planting and TSI. Possible benefits arising from increased production of wildlife, soil and water conservation, forest recreation facilities, and other benefits occasionally claimed to arise from forestry activities are not considered. However, should reliable methods of estimating the size and worth of these claimed benefits become available in the future, such data can be easily incorporated.

Finally, an estimate of the uncertainty associated with investments in subsidized forestry practices is provided, and a number of recommendations are made regarding the implications of this uncertainty for efficient program management.

Forest Practices Considered

The forestry practices for which cost data are given are classified into two groups, based on the nature of public assistance received by the private landowners. One group, "ACP-CFM-supported" practices, includes practices for which private landowners have received both cost-sharing assistance through ACP and technical assistance from the CFM service forester. The second group, "CFM-supported" practices, is composed of those practices undertaken by private landowners with technical assistance from the CFM program. Thus, a given forestry practice may be considered under both "ACP-CFM-supported" and "CFM-supported" practices. The practices considered are:

ACP-CFM-supported:

1. *Planting* forest trees on farmland, farm woodlots, or woodlands for reasons other than prevention of wind or water erosion.
2. *Site preparation* necessary to permit planting of trees or to facilitate natural reseeding.
3. *Fencing* to protect plantations from destructive grazing.
4. *Timber stand improvement* of (a) an immature poletimber stand of forest trees on farmland by thinning and cull tree removal, or (b) (TSI) of a seedling-and-sapling stand by removing or killing competing and undesirable vegetation.
5. *Pruning* crop trees.
6. *Fencing* to protect natural stands from destructive grazing.

CFM-supported:

1. Except for pruning, each of the practices listed above.
2. Marking and other technical service or assistance given to landowners for timber sale or harvesting activities.

Study Areas

Cost data were collected in six sections of the State (fig. 1). Each study area is a CFM Project Area or District served by a single service forester. Study areas were selected in different parts

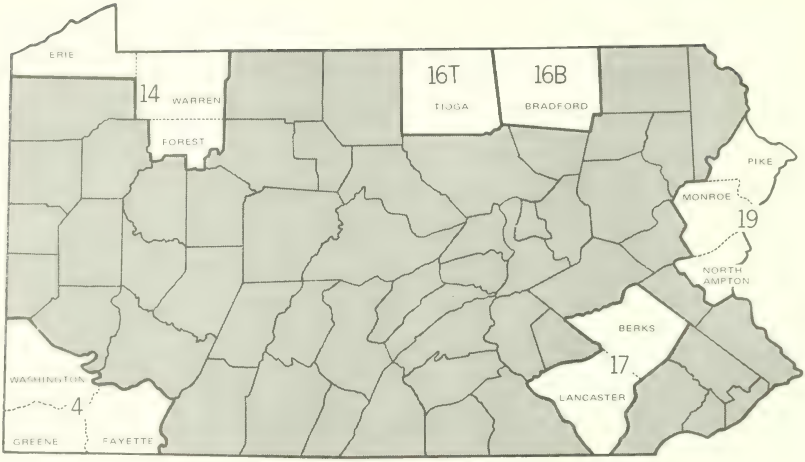


Figure 1.—Each study area is a CFM district or project served by a single service forester. Study areas are identified by their CFM project number designation.

of the State to account for possible regional variations in the costs of providing forestry assistance, and to provide for a comparison of the public costs of ACP-CFM-supported and CFM-supported forestry practices as the relative level of ACP-CFM activity varies. In fiscal year 1964, service foresters in Districts 16B and 16T received more than 100 requests for ACP assistance per county; foresters in Districts 19, 14, and 4 received an average of 24 requests per county; and the forester in District 17 received an average of 5 requests per county.

Districts avoided were: (1) areas where the normal activities of the CFM forester are carried out by state forest-management personnel and (2) areas where the local service forester has been operating for less than 2 years. In the first instance, state forest-management personnel commonly have little time for assistance to private owners. The extent and nature of their CFM activities are quite different from those of the regular, full-time, service foresters. In the second instance, a new service forester spends a greater proportion of his time on general promotional and administrative activities than the more established forester does.

CFM — THE COOPERATIVE FOREST MANAGEMENT PROGRAM

Under the provisions of the 1950 Cooperative Forest Management Act and enabling state legislation, the U.S. Forest Service cooperates with the Secretary of the Department of Forests and Waters to provide private landowners and primary wood processors in Pennsylvania with free technical advice and assistance for managing, harvesting, marketing, processing, and utilizing forest products. Forest Service cooperation takes the form of partial financial support to the Department. In fiscal-year 1965, the Forest Service paid 40 percent of total CFM expenses.

On-the-ground technical services are normally provided by state-employed CFM or service foresters. In areas of the State where most of the forest land is in state ownership, CFM assistance is provided by Department personnel whose principal responsibility is the administration of state forests or other state-owned lands.

Upon an owner's request for technical forestry advice, the service forester recommends needed forestry measures and advises or assists landowners in carrying out these practices. Up to 5 days per year of free assistance is given for such operations as timber harvesting, planting, thinning, pruning, and protection from fire, insects, diseases, and grazing.

Although the service forester is nominally an employee of the CFM program, he is actually the agent who transmits nearly all public forestry programs directed at owners of small woodlands. Frequently the non-CFM programs administered by the service forester are complementary to the objectives of CFM. The forestry aspects of ACP are an example of this complementary relationship. CFM administrators view ACP as an adjunct to their program, and capitalize upon it as a means of stimulating landowners to undertake forestry practices. ACP and CFM are so mutually interdependent that forestry accomplishments obtained under ACP are classified as CFM accomplishments by both the Pennsylvania Department of Forests and Waters and the U.S. Forest Service.

In fiscal-year 1965 there were 33 service foresters in Pennsylvania. Technical assistance was given to 3,250 landowners, 60 percent of whom had not previously used the services of a CFM forester. Planting accomplishments under the program amounted to 4,464 acres; TSI accomplishments, 3,380 acres.

ACP — THE AGRICULTURAL CONSERVATION PROGRAM

Cost-sharing financial assistance for conservation practices through ACP was authorized by the Soil Conservation and Domestic Allotment Act of 1936 (Agricultural Stabilization and Conservation Service 1963). The stated purpose of ACP is to protect the public's interest in the Nation's soil and water resources. Under ACP, landowners are helped to carry out socially desirable conservation practices that would not be undertaken if the total costs had to be assumed by the landowner.

In Pennsylvania, cost-share payments for approved forestry practices account for 2.8 percent of total ACP cost-share payments. The forestry practices that are approved for cost-sharing and the maximum allowable cost-share payment for such practices are established by the State ACP Development Group, a committee whose membership includes a U.S. Forest Service representative.

ACP is administered by county ACP committees through county Agricultural Stabilization and Conservation Service (ASCS) offices. County ACP Development Groups recommend to the county ACP committees which state-approved conservation practices are needed in their respective counties, the funds that should be allocated to these practices, and the cost-shares that should be allowed. County Development Groups may recommend all, some, or none of the practices approved by the State Development Group; and they may suggest maximum allowable cost-share payments below those approved by the State Development Group. The cost-share rate for any given ACP practice is supposed to be the minimum required to induce increased performance of the practice.

The U.S. Forest Service is responsible for developing technical specifications for approved forestry practices and for providing necessary technical forestry assistance to ACP cooperators. In Pennsylvania, field administration is delegated to the Department of Forests and Waters. The CFM service forester is the field-level administering agent. His duties include: (1) determining the need for and the practicality of a specified forestry practice on the ACP cooperator's property, (2) developing technical specifications under which the practice should be carried out, and (3) certifying that the practice has been performed according to specifications. In return for these services, ACP regulations provide for payment of 1 percent of each county's budget to the Department of Forests and Waters for reimbursement of assumed costs. County reimbursements have not been requested by the Department.

In 1964, Pennsylvania landowners received $128,880 in ACP cost-share payments for forestry practices. ACP forestry accomplishments were:

Practice	*Extent*
Planting	3,412 acres
Fencing plantations	2,902 rods
Timber stand improvement	3,467 acres
Fencing natural stands	663 rods
Erosion control on logging roads	15,000 linear feet

Costs of Accomplishments

The total cost of establishing a forestry practice on an acre of privately owned land under ACP or CFM is the sum of the costs incurred by government agencies plus those incurred by the subsidized private landowner. In this study, acreage accomplishment and private and public costs per acre of accomplishment were obtained from records kept by service foresters in the study areas. Data were collected for fiscal-year 1965 (1 July, 1964 to 30 June, 1965).

Acreage accomplishments recorded during the study period do not necessarily correspond to actual on-the-ground-accomplishments for the study period. Completed ACP-CFM and CFM practices were recorded as accomplishments only when the service forester certified an ACP practice as completed or when he definitely knew that a CFM practice for which he had advised a landowner had been completed. A portion of the accomplishments reported at the beginning of the study period was actually completed by landowners before 1 July, 1946. Similarly, practices actually completed by landowners near the end of the study period were not reported as accomplishments until after 30 June, 1965.

ACREAGE ACCOMPLISHMENTS

ACP-CFM- and CFM-supported practice accomplishments in the six study areas during fiscal-year 1965 are shown in table 1.

Table 1.—*ACP-CFM and CFM-supported practice accomplishments in fiscal year 1965, by district*
(In acres)

Practice	All districts	District					
		19	16B	16T	14	4	17
ACP-CFM-supported:							
Planting	917	43	151	83	116	498	26
Site preparation	56	1	—	10	3	42	—
Fencing plantations	161	—	2	44	—	[1]115	—
Timber stand improvement	600	220	127	180	37	33	3
Pruning	31	—	7	24	—	—	—
Fencing natural stands	133	—	75	58	—	[1]—	—
Total	1,898	264	362	399	156	688	29
CFM-supported:							
Planting	399	212	—	15	45	40	87
Site preparation	82	—	12	—	—	66	4
Fencing plantations	25	—	—	—	[1]25	—	—
Timber stand improvement	67	—	2	45	—	17	3
Fencing natural stands	21	—	16	5	[1]—	—	—
Total	594	212	30	65	70	123	94
Harvesting assistance	622	26	31	37	325	93	110
Total	1,216	238	61	102	395	216	204
Total accomplishments	3,114	502	423	501	551	904	233

[1] Accomplishments for fencing plantations and natural stands are combined.

ACP-CFM-supported accomplishments were obtained from ACP performance reports (ACP Form 247). Non-ACP-supported CFM accomplishments (here called "CFM-supported" accomplishments) were obtained by subtracting ACP-CFM accomplishments from the CFM Progress Report record of total ACP-CFM and CFM accomplishments. Excluding the 622 acres of general harvesting assistance, 2,492 acres of accomplishments were reported in the study areas. Tree planting was the most popular practice, accounting for 53 percent of the total. This was followed by timber-stand improvement practices (27 percent) and fencing (14 percent). Site preparation was important only in the southwestern part of the State. Pruning, which accounted for 1 percent of accomplishment, was usually undertaken in conjunction with thinning and cull-tree removal operations.

The average size of ACP-CFM-supported accomplishments per landowner for all practices was 7.9 acres. The average size of planting was 6.4 acres; TSI practices averaged 10.2 acres per landowner (table 2).

ACP supported planting is the most popular practice.— Three-fourths of the total acreage of landowner accomplishments were ACP-supported. By practice, landowners received ACP cost-sharing payments for 70 percent of the planting, 41 percent of the site preparation, 86 percent of the fencing, and 90 percent of the TSI undertaken.

Table 2.—*Average acreage accomplishments per owner for ACP-CFM-supported practices, fiscal year 1965*

(In acres)

Practice	Weighted average	District					
		19	16B	16T	14	4	17
Planting	6.4	3.3	4.2	5.9	7.7	7.9	13.0
Site preparation	4.7	1.0	—	5.0	3.0	12.1	—
Fencing[1]	16.3	—	19.3	5.7	—	16.4	—
Timber stand improvement	10.2	14.7	8.5	9.0	7.4	11.0	3.0
Pruning	3.1	—	3.5	3.0	—	—	—
All practices	7.9	9.1	5.5	7.8	7.4	8.7	9.7

[1] Includes fencing both plantations and natural stands.

Although there is no doubt that ACP encourages planting, the comparison of ACP-CFM and CFM planting accomplishments (table 1) may overemphasize the importance of ACP financial assistance as an incentive for tree planting.

The Agricultural Conservation and Stabilization Service, the Soil Conservation Service, and other agricultural agencies that deal with farmers and other small landowners frequently encourage their clients to plant trees under ACP. When this occurs, ACP is likely to be active. In Districts that have an active ACP, the service forester may receive so many requests for ACP technical assistance that he finds it unnecessary, or does not have time, to solicit planting under the CFM program. Also, service foresters nearly always inform a CFM client of the availability of ACP cost-sharing if the practice he is considering is approved by ACP. To the degree that CFM cooperators apply for ACP cost-sharing on the basis of this knowledge, potential CFM accomplishments are traded for ACP-CFM accomplishments.

Tree species planted with financial assistance from ACP are shown in table 3. White and red pine were the most widely planted, accounting for more than half of all planting. Black locust, the only hardwood species extensively planted, was popular with farmers in Districts 16B, 14, and 4 as a future source of fence posts and grape stakes. Landowners who planted more than 5 acres usually planted two or more species, one of which was spruce or larch.

Market conditions determine the importance of the ACP-supported TSI.—The relative importance of ACP-CFM-supported TSI practices in Districts 19 and 16T reflect market conditions in these areas. At the time of the study, neither of these areas had a market for the small and cull material that is normally removed in TSI operations. TSI operations did not yield salable products and were therefore eligible for ACP-support payments. In contrast District 14 had an active and readily available market for pulpwood, and noncommercial thinning and cull-tree removal were relatively uncommon in this district.

The presence of active timber markets in District 14 also

Table 3.—*Tree species planted with ACP cost-share payments in the study areas, fiscal year 1965*

Species	Percent
Austrian pine	5
Red pine	11
White pine	41
Other pines	1
Larch	9
Norway spruce	10
White spruce	3
Black locust	8
Not reported	12
Total	100

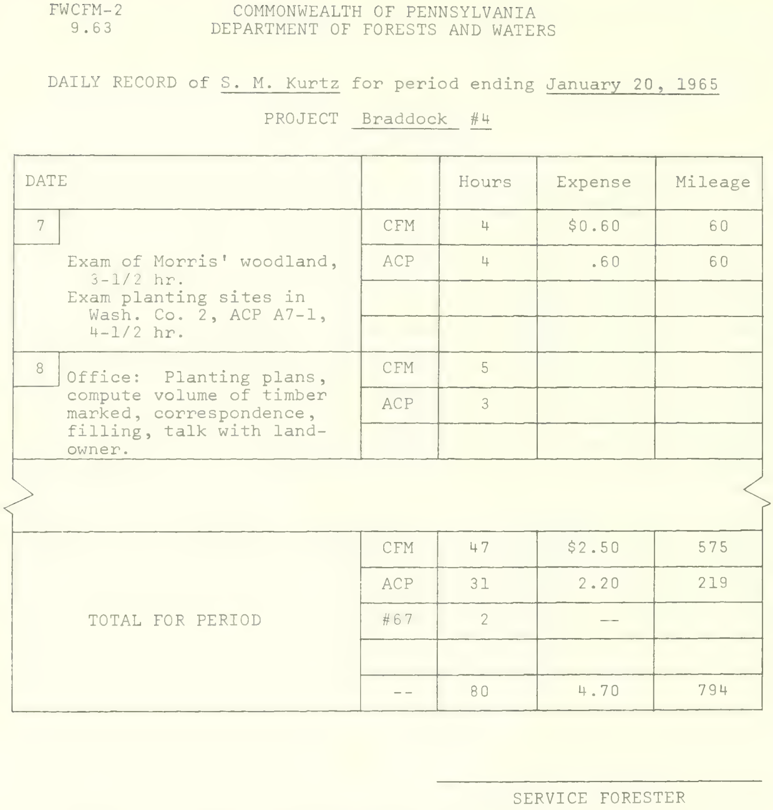
explains why assistance in harvesting operations is a relatively important CFM activity in this district. More than half of the total acreage of harvesting assistance given landowners by the six cooperating service foresters was in this district.

PUBLIC COSTS

The social or public costs of CFM-ACP- and CFM-subsidized forestry practices include: (1) the overhead or indirect costs of the programs; (2) direct or variable costs incurred by service foresters in providing solicited technical services; and (3) for ACP-CFM practices, the cost-sharing payment. For planting, an additional public cost is the difference between planting-stock production costs and the price charged private landowners for planting stock.

Overhead Costs

Overhead costs include the costs of supervision, secretarial services, office facilities, professional tools and equipment, and similar items. Since this study is about the profitability of individual ACP-CFM and CFM practices rather than about the profitability of the ACP and CFM program as a whole, overhead costs were not considered.



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COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF FORESTS AND WATERS

DAILY RECORD of S. M. Kurtz for period ending January 20, 1965

PROJECT Braddock #4

DATE		Hours	Expense	Mileage
7 Exam of Morris' woodland, 3-1/2 hr. Exam planting sites in Wash. Co. 2, ACP A7-1, 4-1/2 hr.	CFM	4	$0.60	60
	ACP	4	.60	60
8 Office: Planting plans, compute volume of timber marked, correspondence, filling, talk with landowner.	CFM	5		
	ACP	3		
TOTAL FOR PERIOD	CFM	47	$2.50	575
	ACP	31	2.20	219
	#67	2	--	
	--	80	4.70	794

SERVICE FORESTER

Figure 2.—Sample daily record of a cooperating service forester.

Direct Costs

Three types of direct costs are incurred by the service forester who provided technical assistance to landowners: salary, transportation, and subsistence. Subsistence expenses are almost entirely the cost of meals eaten away from the forester's headquarters. The extent of these direct costs was determined from the service foresters' daily records of the number of hours spent on various professional activities, and the mileage and meals chargeable to these activities (fig. 2).

The amount of salary chargeable to individual practices was obtained by summarizing the daily activities of the cooperating service foresters into three classes:

1. **Recorded ACP-CFM and CFM activities:** Time spent on activities directly related to forestry measures supported by (a) ACP-CFM, and (b) by CFM alone.

2. **Unrecorded activities:** Time spent on activities that may result in on-the-ground accomplishments of practices not classified under or related to "recorded activities". These activities include: (a) insect and disease survey and control, (b) fire prevention and suppression, (c) forestry activities on State-owned lands, (d) and forestry work undertaken on PL-566 watersheds. Many of these activities are undertaken by service foresters but are not legitimate CFM functions. The State therefore does not charge the costs of the activities to the CFM program.

3. **Supporting activities:** Time spent on activities that do not directly result in on-the-ground accomplishments but are necessary for accomplishment of "recorded" and "unrecorded" activities. Five classes of supporting activities are recognized:

   - Assistance to landowners that is not related to a specific practice.
   - CFM records and administrative duties.
   - Official meetings other than CFM meetings.
   - Information and education activities (I&E).
   - Vacation and other paid leave.

The proportion of total time spent by cooperating service foresters on each of these three classes of activities is given in table 4. Time charged to recorded activities includes both the time spent servicing clients who actually undertook forestry practices and time spent servicing those who did not. In some districts, the time spent visiting landowners who had considered, but did not undertake, forestry practices represents a substantial part of total time. In at least one district, more than half of the ACP-referred landowners contacted by the service forester did not complete a forestry practice (table 5).

In total, cooperating service foresters visited 365 ACP clients

Table 4.—*Time spent by cooperating service foresters, pursuing different classes of activities, fiscal year 1965*
(In percent)

Activity	Weighted average	District 19	16B	16T	14	4	17
Recorded activities:	30	39	34	32	23	18	35
ACP-CFM practices	20	29	25	21	11	6	29
CFM practices	10	10	9	11	12	12	6
Unrecorded activities	14	15	7	16	5	27	11
Support activities:	56	46	59	52	72	55	54
General assistance	10	5	13	8	17	10	9
Administrative	21	15	27	22	28	14	17
Meetings	6	7	5	4	7	5	6
Information & education	6	8	2	2	5	13	4
Paid leave	13	11	12	16	15	13	18
All activities	100	100	100	100	100	100	100

in fiscal-year 1965. One-third of these landowners failed to complete the forestry practice they applied for. For individual practices, the following percentages of landowners failed to complete the practice applied for:

Practice	*Percent*
Planting	12.2
Site preparation	40.0
Fencing plantations	40.0
Timber stand improvement	48.7
Pruning	65.5
Fencing natural stands	63.5

Time associated with recorded ACP-CFM and CFM practices for which there were no on-the-ground accomplishments was charged to practices for which there were accomplishments. Charges were allocated to completed practices in proportion to the acreage accomplishments for these practices. For ACP-CFM practices, time associated with visits to county ASCS offices were charged to the practice the visit was in reference to. If the nature of the practice was not specified, or if the visit was for general administration, time was allocated to individual practices according to the acreage distribution of ACP-CFM practice accomplishments.

Table 5.—*Number of owners applying for and completing ACP-supported forestry practices, by district, fiscal year 1965*

District	Owners who requested ACP assistance	Owners completing practice applied for
19	32	29
16B	97	58
16T	108	51
14	31	21
4	93	79
17	4	3
Total	365	241

Within each district, the number of hours devoted to supporting activities was prorated to recorded and unrecorded activities according to the percentage of total service-forester time accounted for by these activities. For example, in District 19 the service forester devoted 46 percent of his time to support activities and 54 percent to recorded and unrecorded activities. Of this 54 percent, 28 percent was for unrecorded and 72 percent for recorded activities. Thus, 28 percent of total support time was allocated to unrecorded activities, and 72 percent was allocated to recorded activities.

Support time charged to recorded practices was charged to individual ACP-CFM and CFM practices in proportion to the number of acres of practice accomplishments under these programs. Acreage rather than forester time distributions were used since there was no clear relationship between time spent on a given practice and accomplishments for that practice.

Time data were converted to dollars on the basis of the average salary of cooperating foresters: $6,100 per year. The results of these allocations are shown in table 6. For all districts, support time allocated to recorded activities accounted for 58 percent of the total salary charged to 'ACP-CFM practices and 72 percent of total salary costs for CFM practices.

Mileage and miscellaneous expenses.—Direct and allocated mileage and miscellaneous expenses are also shown in table 6. Mileage was charged at $.055 per mile, the rate paid by the

Table 6.—*Total costs of recorded activities and allocated support for providing technical assistance to landowners for forestry practices under the CFM program, by study area, fiscal year 1965*

Program and expense	All districts	District					
		19	16B	16T	14	17	4
				ACP-CFM-SUPPORTED			
Salary:							
Recorded	$ 4,492	$1,139	$1,157	$ 963	$ 343	$ 172	$ 718
Allocated support	12,634	1,892	3,377	2,147	1,500	482	3,236
Mileage and other:							
Recorded	1,530	496	320	151	182	38	343
Allocated support	1,903	393	643	234	177	87	369
Total:							
Recorded	6,022	1,635	1,477	1,114	525	210	1,061
Allocated support	14,537	2,285	4,020	2,381	1,677	569	3,605
				CFM-SUPPORTED			
Salary:							
Recorded	3,335	490	368	616	663	844	354
Allocated support	8,820	1,252	655	486	3,061	2,664	702
Mileage and other:							
Recorded	643	163	112	62	102	151	53
Allocated support	1,737	363	104	59	456	639	116
Total:							
Recorded	3,978	652	480	678	766	995	407
Allocated support	10,557	1,615	759	545	3,517	3,303	818

Department of Forests and Waters for use of State-owned automobiles.

ACP-CFM mileage and miscellaneous expenses were prorated to individual practices according to the percentage of total ACP-CFM accomplishments represented by each ACP-CFM practice. Non-ACP mileage and miscellaneous expenses were charged to support, recorded, and unrecorded activities in proportion to the time spent on these activities. Expenses thus allocated to support activities were prorated to recorded ACP-CFM and CFM practices according to the percentage of total acreage accomplishments represented by individual practice accomplishments.

Costs per acre.—Direct public costs per acre of accomplishment were obtained by dividing the total direct costs by the acreage of practice accomplishments. These data are given in table 7. The average direct cost of providing technical advice and service for all ACP-CFM and all CFM accomplishments other than harvesting assistance was $10.80 per acre. For all ACP-CFM-supported practices the average for all districts was $10.83 and for CFM-supported practices it was $10.68. Costs of providing harvesting assistance to landowners averaged $12.11 per acre.

For TSI practices, the average cost of providing assistance was $13.25, per acre, which was $2.82 greater than the cost of providing assistance for planting. This was expected because the service forester had to take time to teach the landowner proper TSI tree-marking procedures, or do the actual marking job himself. The cost of providing technical advice for each of the practices of site preparation and fencing of plantations was less than for planting.

Technical advice for site preparation and fencing is normally given in conjunction with planting advice. Similarly, advice for fencing natural stands or for pruning is less expensive than that for thinning and cull-tree removal. In general, when two or more practices are undertaken by a landowner, each practice bears a portion of the cost for traveling to the co-operator's woodlands and the cost of time spent in establishing a working relationship with the landowner.

Table 7.—*Direct costs per acre of accomplishment for providing technical assistance for forestry practices under the CFM program, by district, fiscal year 1965*

(In dollars per acre)

District	Program and weighted average	Landowner accomplishments							
		All practices	Planting	Site preparation	Fencing plantations	Timber stand improvement	Pruning	Fencing natural stands	Harvesting assistance
19	ACP-CFM	$14.85	$16.45	—	—	$14.53	—	—	—
	CFM	9.42	9.42	—	—	—	—	—	$10.37
	Weighted average	12.43	10.63	—	—	14.53	—	—	10.37
16B	ACP-CFM	15.19	14.56	—	$27.17	16.22	$23.79	$13.58	—
	CFM	17.21	—	$15.23	—	47.97	—	14.86	23.33
	Weighted average	15.34	14.56	15.23	27.17	16.71	23.79	13.80	23.33
16T	ACP-CFM	8.76	10.45	5.88	6.64	9.10	8.66	7.41	—
	CFM	10.36	13.70	—	—	9.32	—	9.73	14.83
	Weighted average	8.98	10.95	5.88	6.64	9.15	8.66	7.59	14.83
14	ACP-CFM	13.92	13.20	18.59	—	16.60	—	—	—
	CFM	11.03	12.35	—	[1]8.67	—	—	[1]—	10.80
	Weighted average	13.17	13.00	18.59	8.67	16.60	—	—	10.80
4	ACP-CFM	6.98	6.65	6.32	6.55[1]	10.19	—	[1]—	—
	CFM	5.47	8.07	4.05	—	4.89	—	—	5.94
	Weighted average	6.58	6.75	4.93	6.55	6.99	—	—	5.94
17	ACP-CFM	26.89	25.09	—	—	42.53	—	—	—
	CFM	18.49	15.81	16.96	—	89.40	—	—	17.55
	Weighted average	20.47	17.94	16.96	—	65.96	—	—	17.55
All districts									
	ACP-CFM	10.83	10.11	8.88	6.83	13.29	12.07	10.88	—
	CFM	10.68	11.17	4.05	8.66	12.94	—	13.63	12.11
	Weighted average	10.80	10.43	6.55	7.08	13.25	12.07	11.26	12.11

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[1] Fencing of natural stands and of plantations are combined under "Fencing plantations."

Differences in average costs between study areas correspond closely to the differences in the level of practice accomplishments. Low costs were experienced when high levels of accomplishment were obtained. And high costs occurred when accomplishments were low. The proportion of the service forester's time specifically devoted to the considered practices was also related to costs: the greater the time spent on a practice, the higher the cost. A comparison of data for Districts 14 and 17 (tables 1, 4, and 7) illustrates these relationships. The forester in District 4 spent less of his total time on the recorded activities than did other foresters, reported more acres of practice accomplishments, and had the lowest costs per acre of landowner accomplishment. The forester in District 17 spent 35 percent of his time on recorded activities, had the lowest record of total accomplishments, and experienced the highest costs per acre. In general, the relationships held, for all study areas.

Sample data indicate that the relationships between per-acre costs, level of accomplishments, and time spent on a practice were mainly the results of the following interrelated factors: (1) differences in levels of ACP activity among study areas; (2) the seasonality of forestry activities (fig. 3); and (3) the efficiency of the individual service forester. It appears that the seasonal nature

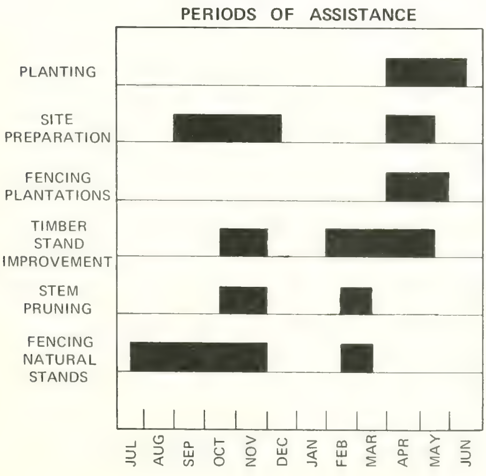

Figure 3. — The time period during which assistance for forestry practices is provided by service foresters in the study areas follows seasonal patterns. Planting and related fencing are normally done in the spring, site preparation in the fall, and TSI activities in early fall and late winter.

of forestry activities and the relative importance of ACP as a vehicle for undertaking forest practices strongly influence the amount of time a service forester spends advising individual landowners. Time devoted to servicing landowners in turn affects the costs of providing assistance on a per-acre-of-accomplishment basis.

For example, most county ASCS offices do not begin to process landowner applications for approval to undertake ACP-supported planting until mid- or late-January. It usually takes the ASCS office 1 to 2 months to process an ACP application and to submit the ACP referral sheet to the service forester determining technical needs. To insure survival, planting must be done before May. Certification of planting accomplishments must be turned into the ACP office in June. This means that the service forester has about 3 months to contact the applying landowners, draw up technical specifications, process orders for seedlings from a State nursery, and certify that planting has been undertaken (fig. 4). During this same 3-month period he must also provide assistance to landowners who intend to plant without ACP support. If the number of ACP cooperating landowners interested in planting is large, service time for other forestry practices (other than site preparation and fencing of plantations) is necessarily postponed until after the planting season. Postponement of nonplanting service activities is made even more necessary if other types of important seasonal activities, such as fire suppression and insect and disease surveys, are also conducted during the planting season. A similar situation ocurs for TSI activities during the fall.

In effect then, in areas where there is an active interest in ACP-CFM-sponsored forestry activities, the service forester specializes in providing assistance for different types of activity at different times of the year. He also limits the amount of service he gives individual landowners. And since ACP supplies him with a list of people who have expressed an interest in a particular forestry practice, he spends a relatively small percentage of his time encouraging landowners to undertake forestry practices. Those promotional activities he does undertake are also

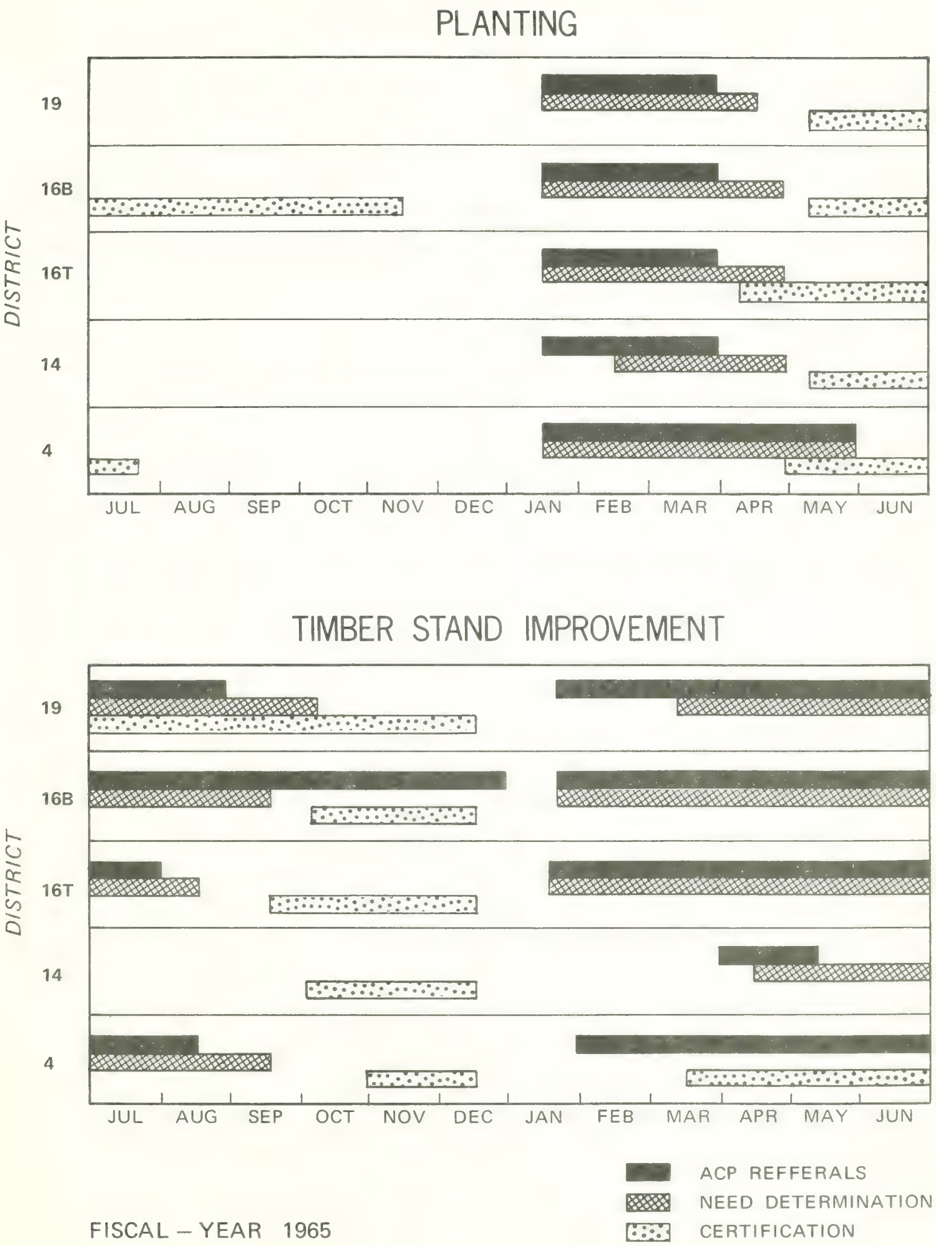

Figure 4.—The time period over which service foresters received ACP referrals, determined practice needs, and certified accomplishments for planting and for TSI practice varied by district.

likely to be relatively successful. Locally favorable attitudes toward forestry practices are generated by ACP and various public agricultural agencies, such as the Soil Conservation Service, that encourage landowners to undertake forestry practices under ACP. As a result, costs per acre are low.

Alternatively, in districts where there is a relatively inactive ACP-CFM program, costs per acre of accomplishment are high. In these districts the service forester does not specialize by season. Accordingly, he spends more time with individual landowners and provides them with more service. And he spends a good portion of his time trying to overcome landowner apathy in forestry practices. Without the deadlines imposed by ACP, service foresters also appear to make less efficient use of their time than do foresters who are actively engaged in ACP-related forestry. District foresters who reported low ACP-CFM accomplishments had larger and more persistent backlogs of unanswered requests for CFM assistance than did the foresters who reported high ACP-CFM accomplishments. If these requests for assistance had been met, accomplishments might have increased and costs per acre decreased.

ACP Cost-Sharing Payments

ACP cost-sharing payments are shown in table 8. The payments shown, ranging from $1.02 to $21.88 per acre, are usually the maximum that was allowed. There are two reasons for this. First, when a landowner received tentative approval for a practice, the maximum payment for the number of practice units to be undertaken was set aside by the ASCS office. This was done so that approval would not be given for more ACP practice units than total ACP funds allowed. Since the amount of ACP funds available to a county in the next fiscal-year was based partially on levels of ACP expenditures during the current year, and since the maximum funds had been committed, they were usually paid. Second, landowners knew the maximum cost-share rates and billed accordingly. A landowner will seldom turn in a bill that will not permit him to receive the maximum allowable payment.

In each of the study areas, ACP payments for planting covered

Table 8.—*Average cost-sharing payment per acre for ACP-supported practices, by study area, fiscal year 1965*
(In dollars per acre)

Practice	Weighted average	District					
		19	16B	16T	14	4	17
Planting	$17.32	$19.09	$17.52	$18.22	$21.88	$15.85	$18.28
Site preparation	6.03	—	—	19.00	18.31	5.00	—
Fencing plantations	3.17	—	16.66	8.19	—	[1]1.02	—
Timber stand improvement	20.00	20.00	20.00	20.00	20.00	20.00	—
Pruning	10.74	—	9.75	11.02	—	—	—
Fencing natural stands	3.30	—	2.13	4.81	—	[1]—	—

[1] Fencing natural stands is included under fencing plantations.

80 percent of the total cost of planting, but not in excess of $2.50 per 100 trees or $25.00 per acre, whichever was smaller. Average payments in the individual study areas were calculated on the basis of the number of trees required to plant an acre according to the spacing normally recommended by the local forester.

Cost-share payments for site preparation were also 80 percent of total costs. The maximum payment allowed varied according to the nature of site preparation performed. A maximum of $5.00 per acre was usually allowed for removal of small ground cover by rotary mowing, $19.00 per acre for removing competing growth with a root rake, and $10.00 per acre for girdling, felling, or poisoning of an undesirable overstory. The total acreage for different types of site preparation was weighted by the respective cost-share to determine an average figure for each district.

Cost-share for fencing was 50 percent of total costs, but not in excess of some specific amount per rod of fencing. The maximum amount varied between counties, and within a county by type of fencing. Average per-acre cost-share payments were calculated on the basis of the total rods of fence constructed, total fencing cost-share payments actually paid, and number of acres enclosed by fencing.

The standard payment for improving a stand of forest trees is the smaller of $20 per acre or 80 percent of the cost. Although different types of TSI operations are undertaken under the ACP and a variety of methods are often used for similar operations (for example, felling, girdling, or chemical poisoning for thinning and cull tree removal), the maximum of $20 per acre is nearly always paid. This was the rate used in our cost calculations.

Payments for pruning were $.075 per linear foot pruned but not in excess of 80 percent of costs. Average acre cost-share payments for each district were calculated, using the $.075 rate and the average number of feet pruned per acre in the district.

Planting Stock Production Costs

Virtually all the seedlings planted by private landowners in conjunction with the CFM program are obtained from nurseries operated by the Pennsylvania Deartment of Forests and Waters.

Private landowners purchase seedlings from State nurseries at $7 per thousand, or $4 for 500 seedlings, delivered to a central point in each county. These prices are considerably below production costs. For purposes of this analysis, we assumed that the public cost of supplying seedlings to private landowners at subsidized prices is $7 per acre of land planted.

LANDOWNER COSTS

ACP-CFM supported practices.—The initial investment that a landowner makes in an ACP-supported forestry practice is equal to that portion of practice establishment cost not covered by the cost-sharing payment. In theory, this is what is left after the appropriate percentage of total cost has been paid by ACP. In practice, landowners frequently submit bills that have been influenced more by their knowledge of the maximum cost-sharing payments available than by actual costs experienced. Because costs reported by landowners are unreliable indicators of actual costs, local contract rates were used whenever possible.

Contract-rate-based estimates of private investment in ACP-supported planting are given in column (4) of table 9. Contract rates averaged 2c per tree for machine planting and 3c per tree for hand planting, exclusive of the cost of seedlings. Planting costs shown for the individual study areas are for the most common methods of planting and plantation spacing in the area. Private costs were calculated by subtracting seedling costs and contract planting rates from the cost-share payment. Private costs ranged from $10.92 per acre in District 19 to $1.46 per acre in District 17.

Local contract rates were also used to calculate private investments in timber stand improvement practices. The difference between contract rates and ACP cost-share payments, which varied from $10 to $5 per acre, was the cost to the landowner.

For site preparation, pruning, and fencing, we assumed that the cost-share payments represented 80 percent, 50 percent, and 50 percent, respectively, of total practice costs, and that the landowner absorbed the remainder. These practices are not normally undertaken by contractors.

Table 9.—*Public and private costs of an acre of ACP-CFM- and CFM-supported forestry practice accomplishment, by practice and district, fiscal year 1965*

(In dollars per acre)

District (1)	Practice (2)	ACP-CFM-supported			CFM-supported		
		Public[1] (3)	Private (4)	Total (5)	Public[2] (6)	Private (7)	Total (8)
19	Planting	$42.53	$10.92	$53.45	$16.42	$30.00	$46.42
	Timber stand improvement	34.53	10.00	44.53	—	—	—
	Harvesting assistance	—	—	—	10.37	—	10.37
16B	Planting	39.08	4.91	43.99	—	—	—
	Site preparation	—	—	—	15.32	23.75	39.07
	Fencing plantations	43.83	4.16	47.99	—	—	—
	Timber stand improvement	36.22	5.00	41.22	47.97	25.00	72.97
	Pruning	33.54	2.44	35.98	—	—	—
	Fencing natural stands	15.71	.53	16.24	14.86	2.84	17.70
	Harvesting assistance	—	—	—	23.33	—	23.33
16T	Planting	35.67	5.10	40.77	20.70	23.32	42.02
	Site preparation	24.88	4.75	29.63	—	—	—
	Fencing plantations	14.83	2.05	16.88	—	—	—
	Timber stand improvement	29.10	5.00	34.10	9.32	25.00	34.32
	Pruning	19.68	2.75	22.43	—	—	—
	Fencing natural stands	12.22	1.20	13.42	9.73	6.01	15.74
	Harvesting assistance	—	—	—	14.83	—	14.83
14	Planting	42.08	6.00	48.08	19.35	27.88	47.23
	Site preparation	36.90	4.58	41.48	—	—	—
	Fencing	—	—	—	8.67	[3]11.20	19.87
	Timber stand improvement	36.60	7.00	43.60	—	—	—
	Harvesting assistance	—	—	—	10.80	—	10.80

4	Planting	29.50	[4]3.12	32.62	15.07	18.97	34.04
	Site preparation	11.32	1.25	12.57	4.05	6.25	10.30
	Fencing[5]	7.57	.26	7.83	—	—	—
	Timber stand improvement	30.19	[4]5.00	35.19	4.89	25.00	29.89
	Harvesting assistance	—	—	—	5.94	—	5.94
17	Planting	50.37	1.46	51.83	21.81	19.71	42.52
	Site preparation	—	—	—	16.96	[3]10.00	26.96
	Timber stand improvement	62.53	5.00	67.53	89.40	25.00	114.40
	Harvesting assistance	—	—	—	17.55	—	17.55

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[1] Includes the ACP cost-share payment, the direct costs of providing technical assistance, and the planting stock production cost subsidy.

[2] Includes the costs of providing technical service, and the planting stock production cost subsidy.

[3] Estimate.

[4] Assumes a contract rate of $25.00 per acre.

[5] Includes fencing both plantations and natural stands.

CFM-supported practices.—Data describing the private costs of undertaking CFM-supported forestry practices without ACP assistance were not collected. We derived the estimates of private costs shown in column 7, table 8. These costs were assumed to be equal to the sum of ACP cost-share payments (table 8) and the private investments for identical practices undertaken with ACP support (column 4, table 9).

For CFM harvesting assistance, a practice for which there is no ACP-CFM counterpart, private costs per acre were assumed to be negligible.

TOTAL COSTS PER ACRE

Total costs of ACP-CFM- and CFM-subsidized forestry practices in the individual study areas are shown in columns 5 and 8, table 9. For comparable practices, costs ranged from a high of $114.40 per acre for non-ACP-supported TSI in District 17 to a low of $7.83 for ACP-CFM fencing in District 4. Because private cost estimates for CFM practices are based on private costs for ACP-CFM practices, differences between total costs per acre for any given ACP-CFM-supported practices and identical CFM-supported practices within a given district are entirely due to the differences in the costs of providing technical advice and service.

The explanations of differences in practice-accomplishment costs between study areas have been noted in previous sections dealing with the components of total costs. Briefly, in districts where total ACP-CFM accomplishments are high, average cost per acre of all ACP-CFM-supported and all non-ACP-supported accomplishments are low. Alternatively, low levels of ACP-CFM accomplishment lead to high costs per acre of accomplishments.

Average cost data for all study areas are shown in table 10. Excluding harvesting assistance to landowners, total average cost for all ACP-CFM practices ($34.30) was $3.31 less than the total cost for comparable CFM practice accomplishments ($37.61.) As expected, significant differences occurred in the incidence of accomplishment costs. For all ACP-CFM practices, public costs were 87 percent of total cost. For comparable non-ACP-supported CFM accomplishments, public cost accounted for 41 percent of total costs.

Estimating Stumpage Returns from Planting and TSI

Measurements of profitability of the investment made in establishing a forestry practice require knowledge of both the costs of establishment and the market value of the products eventually produced.

Table 10.—*Weighted average public, private, and total costs per acre for practice accomplishments for all study areas, fiscal year 1965*
(In dollars per acre)

Item	Public	Private	Total
ACP-CFM-SUPPORTED			
Planting:			
Planting only	$34.43	$ 4.28	$38.71
With site preparation	49.34	6.31	55.65
With fencing	44.43	5.08	49.51
With site preparation and fencing	59.34	7.11	66.45
Site preparation	14.91	2.03	16.94
Fencing plantations	10.00	.80	10.80
Timber stand improvement	33.29	6.95	40.24
Pruning	22.81	2.68	25.49
Fencing natural stands	14.19	.82	15.01
Total ACP-CFM	29.81	4.49	34.30
CFM-SUPPORTED			
Planting:			
Planting only	18.17	26.16	44.33
With site preparation	24.50	35.15	59.65
With fencing	26.84	37.36	64.20
With site preparation and fencing	33.17	46.35	79.52
Site preparation	6.33	8.99	15.32
Fencing plantations	8.67	11.20	19.87
Timber stand improvement	12.94	25.00	37.94
Fencing natural stands	13.63	3.59	17.22
Total	15.38	22.23	37.61
Harvesting assistance	12.11	—	12.11
Total CFM	13.71	22.23	24.56
ACP-CFM and CFM	$23.52	$ 8.72	$30.50

RETURNS FROM PLANTING

Estimates of the stumpage output from forest plantations were made for white pine, red pine, larch, and Norway spruce. All together, these four species accounted for at least three-fourths of the total planting undertaken in the study areas (table 3). Published and unpublished yield tables were used to determine possible gross yields. Yield tables and their sources are given in the appendix, tables 16 to 19.

For each species, an attempt was made to provide a comprehensive coverage of possible investment alternatives. Several rotation ages, site conditions, and final products were considered. These are shown in table 11.

Three site indexes were considered for white pine, red pine, and larch; and two for Norway spruce. Site index levels were chosen to conform to the site-productivity classification used by the Pennsylvania Department of Forests and Waters. The analytical procedure described by Webster *(1960)* was used to equate site indexes and site-productivity classes. In each case, the highest site index corresponded to site-productivity class I, the next highest to a class II site, and the lowest to a class III site.

A minimum of four alternative rotation ages spaced 10 and 20 years apart were considered for each species. Volume of timber that was to be removed during thinnings and final harvest cuttings are shown in the yield tables in the appendix. Timber products to be harvested were chosen on the basis of current and projected market conditions. Sawlogs were assumed to be the most likely product from larch and white pine plantations. For red pine, a market for both pulpwood and sawlogs was assumed. For Norway spruce plantings, a pulpwood market seemed more likely than a sawlog market.

Estimates of future stumpage prices were based on 1965 market prices for softwoods in Pennsylvania and on expected price increases. Because market conditions vary between study areas, two price levels were considered for each species. For sawlogs, prices ranged from $43.95 to $30.00 per thousand board feet. Pulpwood prices ranged from $7.50 to $3:50 per cord. With the exception of white pine, an annual percentage

Table 11.—*Stocking levels, site indexes, rotation ages, products, and stumpage prices considered for softwood plantations, by species*

Species	Stocking level	Site indexes[1]	Rotation ages	Products	Stumpage price[2]	
					Current price	Annual increase
	Percent	*Feet*	*Years*			*Pct.*
White pine	90	80,70,40	50,60,70,80,100,120	Sawlogs	$43.95	1.1
					30.00	.5
Red pine	90	60,50,45	55,75,95,105	Sawlogs	43.95	1.1
				Pulpwood	5.50	.5
				Sawlogs	30.00	1.1
				Pulpwood	3.50	.5
Larch	80	90,80,40	30,40,50,60,70	Sawlogs	35.00	1.1
					30.00	1.1
Norway spruce	80	80,60	20,30,40,50,60,70	Pulpwood	7.50	1.1
					5.50	1.1

[1] Site index is the average height of dominant and codominant trees at 50 years of age.

[2] Prices for sawlog stumpage are dollars per thousand board feet; for pulpwood, dollars per cord.

increase in price of 1.1 percent for sawlogs and 0.5 percent for pulpwood was used for both the high- and low-price options. For white pine, an annual price increase of 1.1 percent was applied to the high-price option and 0.5 percent to the low-price option. The lower price growth rate for the low-price option was made under the assumption that there would be comparatively little increased demand for white pine stumpage in those areas of the State where current stumpage prices are lower than the state-wide average.

RETURNS FROM HARDWOOD TIMBER STAND IMPROVEMENT

The term *timber stand improvement* has been used to cover two silvicultural practices: (1) a combination of cleaning and liberation or cull-tree removal in seedling-and-sapling stands, and (2) precommercial thinnings and cull-tree removal in previously unmanaged poletimber stands. On the basis of Pennsylvania's forest inventory, noncommercial thinnings similar to those subsidized by ACP and CFM are most likely to occur in northern hardwood, oak, or cove hardwood stands. Cleaning and cull-tree removal are most likely to occur in the northern hardwood or oak stands. Typical site indexes and related site-productivity classes for these forest types are shown in table 12. Yield tables

Table 12.—*Stand timber types, site indexes, and site-productivity classes subject to financial analysis for cleaning and cull-tree removal and thinning*

Stand type description	Site index corresponding to site-productivity class[1]		
	Site class I	Site class II	Site class III
CLEANING AND CULL-TREE REMOVAL			
Northern hardwoods	90	70	—
Oak	80	60	30
THINNING			
Northern hardwoods	90	70	—
Oak	80	60	30
Cove hardwoods	100	80	—

[1] Site index is defined as the average height of dominant and codominant trees at 50 years of age.

for the sites identified in table 12 are given in tables 20 and 21.

Estimates of the physical responses to TSI activities given in tables 20 and 21 are based on the stand-table projections made by Webster (1960). Webster's projections were based on the assumption that cleaning and cull-tree removal (1) will occur in stands between 10 and 15 years of age, (2) will result in an improved species composition and high timber quality, (3) will increase timber yield per acre by permitting commercial thinnings for sawlogs, and (4) will reduce the time required for the stand to reach maturity by 20 years.

For precommercial thinnings in stands that have not received an earlier cultural treatment, Webster assumed that thinnings (1) will occur at stand age 40 in northern hardwood and oak timber types and at age 30 in cove hardwood type, (2) will improve species composition and timber quality, (3) will permit a commercial thinning of approximately 25 percent of available sawlog-sized material 10 years before the final harvest, and (4) will reduce the rotation age by 10 years. The species composition and quality of material removed by the thinning were assumed to be identical to those removed during the final harvest.

The economic response to a TSI activity is the value of the difference between what a treated stand will be worth and what it would have been worth without silvicultural management. For stands that have received a cleaning and liberation cutting, rotations are shorter and total yields are greater than for identical unmanaged stands (table 20). When management begins with a precommercial thinning, the total volume harvested is the same as for unmanaged stands but is of higher quality and is harvested earlier (table 21).

The influence of management upon species composition and timber quality is reflected in the stumpage prices received at the time of harvest. In this study, anticipated future stumpage prices for both managed and unmanaged stands were based on price projections made by Webster *(1960).* They are shown in table 13. Prices shown, ranging from $72.02 to $44.45 per thousand board feet, are the weighted average prices for all species and log grades to be harvested. For treated stands, these were to be

Table 13.—*Estimated future stumpage prices for hardwood sawtimber at harvest for stands that have and have not been subject to a TSI treatment*[1]

(In dollars per thousand board feet)

Timber type	Average future price per thousand[2]	
	With treatment	Without treatment
CLEANING AND CULL-TREE REMOVAL		
Northern hardwoods	$72.02	$63.52
Oak stands	70.44	70.73
THINNINGS		
Northern hardwoods	63.10	44.45
Oak stands	61.92	52.16
Cove hardwood stands	51.16	49.89

[1] Prices shown are for trees removed during the harvest cutting. Prices for volumes removed during thinnings are 90 percent of final harvest price.

[2] Because species mixture and quality vary by site, and because several sites were considered for each treatment, prices vary within each timber type. Variation is less than 1 percent of the prices shown.

received 40 years after the TSI operation in northern and cove hardwoods, and 50 years after TSI in the oak timber type.

Financial Yields

The costs and returns associated with planting and TSI practices are used to determine the financial yields of these practices. The financial yield is the compound rate of interest by which future stumpage returns are discounted so as to equal the cost of establishment at the time of practice establishment. Use of the interest rate of return as a measure of financial yields provides a clear means of comparing possible alternative investments. Investments that yield a high rate of interest are preferable to those that earn a low rate of interest.

A modified version of Row's *(1963)* rate-of-return program was used to calculate financial yields on an electronic computer. And in computing rates of return, we determined the future value of timber yields by multiplying expected physical yields by expected prices. The following assumptions were inherent in this procedure and should be considered in interpreting rate-of-return data:

1. The yield tables (in appendix) are accurate representations of the volumes of timber that will be available for harvest.
2. The entire volume of timber shown in the yield tables will be available for harvest at the specified dates.
3. The available stumpage will be sold at the projected prices at the dates shown in the yield tables.

For planting, four types of establishment activities and associated cost were considered: (1) planting only, (2) planting with site preparation, (3) planting with protective fencing, and (4) planting with site preparation and fencing. Costs used were the weighted averages of direct and private establishment costs in the six study areas (table 10). Accordingly, rate-of-return data are provided for investments in planting, and for investments in planting that require site preparation, or fencing, or both site preparation and fencing. For TSI practices, average TSI cost data shown in table 10 were compared with stumpage returns to cleaning and cull-tree removal, and with stumpage returns from thinning. The use of an identical cost for both these silvicultural operations is in accord with the equality of ACP cost-share payments for these practices.

FINANCIAL YIELDS OF INVESTMENTS

Detailed financial data for average investments in ACP-CFM- and CFM-supported planting and TSI are given in tables 22 to 27. Tables 22 to 25 provide yield data for plantations by species, and by site productivity class, for the financially optimum rotation ages under the high- and low-price assumptions. Returns to average investments in cleaning and cull-tree removal are given in table 26, and returns to precommercial thinnings in table 27.

In each of the appendix tables, financial yields at the financially optimum rotation age are given for three sources of investment funds—public, private, and total. Public cost is the direct cost associated with establishing a practice. Cost of administrative overhead and other indirect ACP- and CFM-program costs were excluded. Rates of return earned on direct public investments were determined by comparing these costs with the entire value of stumpage available for harvest at the end of the rotation. The financial yield is therefore one measure of the return to society brought about by public investments in private forestry practices when the objective of these investments is timber production.

Financial yields to private funds represent the rate of return earned by the private landowner on the funds that he invested in practice establishment. Costs associated with holding a stand of timber until harvest were assumed to be equal to the costs of holding land in some other use or condition and therefore were not considered.

Yields to the sum of private and public investments measure the return to the total funds committed by the public and private sectors of the economy in establishing a subsidized practice on private lands. Thus, financial yields to total investments provide a broader measurement of the social return to subsidized forestry practices than is provided by financial yields on the public's investment alone.

A summary of yields to investments in ACP-CFM planting and TSI is given in table 14. Returns to CFM-supported practices are summarized in table 15. In both summaries planting returns are for plantations that did not require site preparation or protective fencing and have been harvested at the financially optimum rotation age.

The summary tables show that, in terms of returns to total establishment investments, it makes little difference if a practice is accomplished with or without financial assistance from ACP. Interest rate returns to total investments in ACP-CFM-supported practices averaged an insignificant 0.3 percent more than returns to total investments in non-ACP-supported CFM accomplishments. Interest returns to public investments in ACP-CFM practices averaged nearly 2 percent lower than investments in CFM practices. Correspondingly, because ACP cost-sharing payments cover 80 percent of private establishment costs, interest returns to private investments in ACP-supported practices averaged 4 per-

Table 14.—*Summary of potential financial yields of ACP-CFM-supported plantings at financial maturity and for TSI practices for public, private, and total establishment investments, by site-productivity class*

(In percent, compound interest)

Practice	Site I	Site II	Site III
PUBLIC INVESTMENT			
Planting:			
White pine	[1]6.9-8.2	5.8-7.0	3.1-3.9
Red pine	7.3-8.3	6.7-7.6	6.1-6.9
Larch	8.9-9.4	7.3-7.7	5.6-5.9
Norway spruce	7.8-9.0	5.8-6.5	—
Cleaning and liberation:			
Oak	5.4	4.1	1.0
Northern hardwoods	7.3	6.3	—
Thinning:			
Oak	7.9	6.0	1.0
Northern hardwoods	11.1	10.2	—
Cove hardwoods	12.2	9.9	—
PRIVATE INVESTMENT			
Planting:			
White pine	11.5-12.9	9.6-10.8	4.8-5.7
Red pine	12.8-14.1	11.9-13.2	10.6-11.6
Larch	15.5-17.6	13.2-13.7	9.6-9.9
Norway spruce	15.9-17.1	10.6-11.3	—
Cleaning and liberation:			
Oak	8.3	7.1	3.2
Northern hardwoods	10.3	9.7	—
Thinning:			
Oak	12.1	10.2	4.4
Northern hardwoods	16.7	15.7	—
Cove hardwoods	18.0	15.5	—
TOTAL INVESTMENT			
Planting:			
White pine	6.6-7.9	5.6-6.8	2.9-3.8
Red pine	7.1-8.0	6.5-7.4	5.9-6.8
Larch	8.6-9.0	7.0-7.4	5.4-5.7
Norway Spruce	7.4-8.6	5.5-6.2	—
Cleaning and liberation:			
Oak	5.1	3.7	1.0
Northern hardwoods	7.0	5.9	—
Thinning:			
Oak	7.4	5.4	1.0
Northern hardwoods	10.5	9.5	—
Cove hardwoods	11.7	9.2	—

[1] The high and low interest rates for planting are rates earned under the high- and low-stumpage price assumptions.

Table 15.—*Summary of potential financial yields of CFM-supported plantings at financial maturity and for TSI practices for public, private and total establishment investments, by site-productivity class*

(In percent, compound interest)

Practice	Site I	Site II	Site III
PUBLIC INVESTMENT			
Planting:			
White pine	[1]8.3-9.6	7.0-8.2	3.9-4.8
Red pine	8.9-9.9	8.2-9.2	7.4-8.2
Larch	11.3-11.8	9.1-9.5	6.8-7.1
Norway Spruce	10.2-11.4	7.2-7.9	—
Cleaning and liberation:			
Oak	7.2	5.9	1.6
Northern hardwoods	9.2	8.4	—
Thinning:			
Oak	10.4	1.0	2.7
Northern hardwoods	14.5	13.5	—
Cove hardwoods	15.8	13.3	—
PRIVATE INVESTMENT			
Planting:			
White pine	7.5-8.8	6.3-7.5	3.4-4.3
Red pine	8.0-9.0	7.3-8.3	6.6-7.5
Larch	9.9-10.4	8.1-8.5	6.1-6.4
Norway spruce	8.9-10.0	6.4-7.1	—
Cleaning and liberation:			
Oak	6.0	4.7	1.0
Northern hardwoods	7.9	7.0	—
Thinning:			
Oak	8.6	11.8	1.0
Northern hardwoods	12.1	11.2	—
Cove hardwoods	13.4	10.9	—
TOTAL INVESTMENT			
Planting:			
White pine	6.3-7.6	5.4-6.5	2.9-3.6
Red pine	6.7-7.7	6.2-7.1	5.6-6.2
Larch	8.2-8.5	6.6-7.1	5.1-5.4
Norway spruce	6.9-8.0	5.2-5.9	—
Cleaning and liberation:			
Oak	5.2	3.9	1.0
Northern hardwoods	6.7	6.1	—
Thinning:			
Oak	7.5	5.6	1.0
Northern hardwoods	10.7	9.7	—
Cove hardwoods	11.9	9.4	—

[1] The high and low interest rates for planting are rates earned under the high- and low-stumpage price assumptions.

cent greater than returns to practices subsidized by technical assistance only.

On site productivity class I and II lands, the most financially desirable practices were precommercial thinning in cove hardwoods and northern hardwoods. Successively less-desirable practices were planting larch or Norway spruce, planting red or white pine, thinning pole-timber-size oak stands, and cleaning and liberating cuttings in northern hardwood and oak stands. On site III lands, planting was more desirable than TSI practices. Practices undertaken on site I lands yielded 0.6 to 2.5 percent more than interest returns to total investments in similar practices undertaken on site II lands. For similar practices, site III lands yielded 0.3- to 10.8 percent less than investments on site II lands.

UNCERTAINTY AND THE FINANCIAL YIELD TABLES

The principal value of the financial yields given in the appendix is that they provide a means of ranking the relative financial desirability of private and public timber-producing investments. Because of the uncertainty associated with the yield data, absolute levels of the financial yields are of limited value. They are based directly on a number of limiting assumptions—assumptions as to possible yields, stumpage values, expenditures, and probability of harvest. How well these assumptions depict future conditions remains to be seen, although a number of factors indicate that the financial yields shown are very highly optimistic.

Physical yield data employed in the analysis are estimated gross yields. No accounting has been made of the probability of loss of growing stock or of entire stands to planting failures, fire, or insects and diseases. Webster *(1960)* estimated that the net output of softwood plantations in Pennsylvania varied between 56 and 81 percent of gross output, depending upon the species planted. Volume loss in hardwoods was estimated to range from 12 to 37 percent of gross output for unmanaged stands, and from 7 to 20 percent of gross output for managed stands. The financial yields given in the appendix would be substantially reduced if these factors were considered.

Another and more important reason for conservative interpretation of absolute levels of financial yields is the basic assumption underlying the financial yields: that the timber produced from program accomplishments will be placed on the market by landowners, and will be purchased and harvested. Data collected during this study indicate that, even if owner objectives are such that they will sell stumpage, a large portion—perhaps a majority—of the net volume of the timber produced as a result of ACP and CFM will not be marketed.

The average size of publicly subsidized planting was less than 7 acres. Landowners who planted more than 5 acres usually planted more than one species. And when more than one species was planted, pines were mixed with spruce or larch. CFM clients occasionally plant a few acres of land for several years in a row, thereby producing a sizable stand of softwoods; but service foresters report that this is not common practice. Given current trends toward capital-intensive high-volume wood-harvesting methods, it does not seem likely that the small and often isolated CFM plantation of mixed species will be attractive to future stumpage buyers. Also, when these tracts are sold, the price received for stumpage may be substantially below the projected market prices. The probability of harvest also is less likely when softwood species, particularly larch and spruce, are planted in a region characterized by hardwood timber types and hardwood timber markets. These species are not widely available in natural stands in Pennsylvania, and it is unlikely that sufficient volumes will become available from plantations to stimulate development of strong markets for them.

The average TSI practice undertaken by CFM clients was about 10 acres in size. Returns to investment for timber very likely would be increased if the average landowner undertook 10 acres of TSI every year for a series of years; but as with planting, this is not common. Since normally only a small portion of the landowner's woodlot is subjected to TSI, there is little effect upon the marketability or value of the stands treated.

Summary & Conclusions

This study provides the administrators of Pennsylvania's CFM program with data they need to monitor the economic efficiency of their program activities. Public and private costs of establishing major CFM- and CFM-ACP-sponsored forestry practices in different parts of the State are given. The practices considered are planting (including either site preparation or protective fencing, or both), cleaning and cull-tree removal, precommercial thinning, pruning, and harvesting and marketing assistance.

The procedure by which cost data were collected is presented in detail with the hope that program administrators will adopt the procedure as an economical means of monitoring program costs. Average establishment costs are compared with estimates of potential stumpage returns, to provide an investment opportunity guide for planting and TSI practices, excluding pruning. The assumed objective of these investments is profitable timber production. The investment guide is based on the rate of interest earned on the weighted average of public and private establishment costs in six CFM districts. The six areas in which data were collected were chosen to account for regional variations in practice establishment costs and differences in levels of CFM program activity.

In the study areas, 2,492 acres of CFM and ACP-CFM forestry practice accomplishments by private landowners, and 622 acres of CFM harvesting assistance were reported. Planting accounted for 53 percent, TSI practices 27 percent, and fencing 14 percent of total landowner accomplishments.

Three-fourths of the accomplishments requiring investments by private landowners were subsidized financially through ACP cost-sharing payments. ACP supported 70 percent of the planting, 89 per cent of the fencing, and 90 percent of the TSI. The average size ACP-supported accomplishment was 7.9 acres per landowner. For planting and TSI the averages were 6.4 acres and 10.2 acres, respectively.

Total direct costs of ACP-CFM and CFM accomplishments ranged from $114.40 to $7.83 per acre. The average public, private and total costs for individual practices are shown in table 28. Non-ACP-supported CFM planting with site preparation and fencing was the most expansive practice, averaging $79.52 per acre. For ACP-CPM practices, the TSI cost ($40.24), was greater than the cost of planting without site preparation or fencing ($38.71). But for non-ACP-supported CFM activities the order was reversed: planting costs ($44.33) exceeded TSI costs ($37.94). The lowest cost activity was that of providing harvesting and marketing assistance to private landowners. The average cost of this service, born entirely by the public, was $12.11 per acre.

The average total cost per acre of all ACF-CFM-supported landowner accomplishments ($34.30) was $3.31 less than the average total cost of all comparable CFM practices ($37.61). Significant differences occurred in the incidence of costs. For practices subsidized by ACP cost-sharing payments, public costs were 87 percent of total costs. For comparable non-ACP-supported CFM practices, public costs accounted for 41 percent of total costs.

Costs varied widely between study areas. Non-ACP-supported TSI showed the most variation, ranging from $29.89 to $114.40 per acre. Total costs of ACP-CFM-supported planting, the most widely undertaken practice, varied from $32.62 to $51.83 per acre. Lowest costs were obtained in districts where the total acreage of ACP-supported forestry accomplishments was large. Conversely, where total ACP-CFM accomplishments were low, costs per acre were high. Sample data therefore indicate that an active ACP program is a prerequisite to low costs. Presumably the same opportunities for efficient operations are available when large numbers of requests for non-ACP-related assistance are received, but these opportunities did not materialize. Service foresters who obtained low ACP-CFM accomplishments had large, persistent backlogs of unanswered requests for CFM assistance. Had the forester been able to honor these requests, accomplishments might have been significantly larger than they were, and costs per acre of accomplishment would have been less.

There may be many reasons why service foresters who had few ACP-CFM accomplishments also reported relatively small non-ACP-supported CFM accomplishments. One explanation is that the absolute deadlines set by county ASCS offices for certification of ACP practice accomplishments cause the service forester to complete a project quickly. ACP practices must be certified as complete by certain specified dates in order for the landowner undertaking the practice to receive a cost-sharing payment. No deadlines are imposed upon the service forester when he services non-ACP-supported CFM cooperators.

Interest rate yields to average total investments in ACP-CFM-supported practices were found to be an insignificant 0.3 percent higher than returns to average total investments in non-ACP-supported CFM practices. For non-ACP-supported CFM practices, the public portion of total investments earned a higher rate of interest return than public investments in identical practices supported by ACP. This was expected, of course, since under ACP the public pays up to 80 percent of the costs incurred by the private landowner in establishing a practice. Correspondingly, private investments in ACP-sponsored practices returned more than private investments in non-ACP-supported practices.

As would be expected, the relative financial desirability of alternative practices was found to vary with the productivity of the forest site. Any practice undertaken on site productivity class III lands was nearly always less desirable than the same or other practices undertaken on site II or site I lands. On sites I and II precommercial thinning in cove hardwoods and northern hardwoods was the most desirable practice. On site III lands, planting was more desirable than thinning or cleaning and liberation. When successful planting must be preceded by site preparation or followed by protective fencing, the additional costs involved caused the order of desirability to change.

Table 29, shows the rates of interest calculated on total investments in ACP-CFM and CFM practices, by site productivity class.

This study indicates that the social return to public investments in the CFM program in Pennsylvania can be increased. Some improvement can be obtained by emphasizing those practices that yield high returns. But if timber production is the major goal more immediate and significant improvements can be obtained by curtailing activities in districts where owner accomplishments are small and by discouraging practices that have a high degree of uncertainty of eventual harvest.

Districts that report low levels of accomplishment are districts in which per-acre establishment costs are high. High establishment costs, in turn, lead to low returns. For example, site I red pine plantations established at a cost of $25 per acre will earn a potential rate of return that is about 20 percent greater than the potential return on establishment investments of $50 per acre.

Two activities that are likely to produce low timber returns are the typical 10-acre or smaller TSI operation and the 6-acre or smaller plantation of two or more species. Harvesting small acreages of timber is usually more costly than harvesting large tracts of timber and, on the basis of current trends in harvesting methods, will become more so in the future. Even if these small stands will be harvested, stumpage prices very likely will be lower than average. Another practice that is not likely to be profitable for timber production is the planting of softwoods, particularly larch and spruce, in areas where the planted species are not naturally available in volume. Where this condition occurs, markets may not be available for timber that would otherwise be economically mature.

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■

PHYSICAL YIELD TABLES

Table 16.—*Yield table for white pine at 90 percent of full stocking, site indexes 80, 70, and 40*
(In thousand board feet per acre)

Age (years)	Site 80		Site 70		Site 40	
	Thinnings[1]	Harvest	Thinnings[1]	Harvest	Thinnings	Harvest
50	3.8	21.3	3.3	11.1	—	—
60	3.8	28.8	3.3	22.2	—	1.3
70	3.8	41.4	3.3	32.3	—	2.8
80	5.0	41.1	3.6	32.4	—	7.7
90	5.0	—	3.6	—	—	—
100	—	48.7	3.0	40.6	—	14.0
110	—	—	3.0	—	—	—
120	—	55.9	—	45.8	—	18.0

[1] Thinnings at stand ages 50, 60, and 70 apply only to rotation ages 80, 100, and 120.

Source: Yield data were based on *Yield tables for use in study of the economics of eastern white pine production,* unpublished manuscript, USDA Forest Serv. LS. Forest Exp. Sta., St. Paul, Minn., 1957.

Table 17.—*Yield table for red pine, site indexes 60, 50, and 45, based on a basal-area control of 90 square feet per acre*

Age (years)	Thinnings		Harvest	
	Sawlogs	Pulpwood	Sawlogs	Pulpwood
	M bd. ft.	*Cords*	*M bd. ft.*	*Cords*
		SITE INDEX 60		
25	—	8.1	—	—
35	—	10.2	—	—
45	—	11.6	—	—
55	6.5	1.0	18.6	2.0
65	6.5	1.0	—	—
75	6.3	1.0	21.1	2.0
85	5.9	1.0	—	—
95	5.6	1.0	22.6	2.0
105	—	—	23.0	2.0
		SITE INDEX 50		
25	—	5.6	—	—
35	—	7.5	—	—
45	—	8.5	—	—
55	4.7	1.0	14.7	2.0
65	4.6	1.0	—	—
75	4.3	1.0	16.7	2.0
85	4.0	1.0	—	—
95	3.6	1.0	17.7	2.0
105	—	—	17.9	2.0
		SITE INDEX 45		
25	—	—	—	—
35	—	6.4	—	—
45	—	7.2	—	—
55	3.9	1.0	13.0	2.0
65	3.8	1.0	—	—
75	3.5	1.0	14.7	2.0
85	3.2	1.0	—	—
95	2.8	1.0	15.5	2.0
105	—	—	15.6	2.0

Source: Buckman, R. E. *Growth and yield of red pine in Minnesota.* U. S. Dep. Agr. Tech. Bull. 1272, 50 pp. 1962.

Table 18.—*Yield table for larch, site indexes 90, 80, and 40*

(In thousand board feet per acre)

Age (years)	Site index 90		Site index 80		Site index 40	
	Thinnings	Harvest	Thinnings	Harvest	Thinnings	Harvest
30	3.0	9.0	—	—	—	—
40	—	14.0	3.0	11.2	—	—
50	3.6	20.9	—	14.4	2.5	8.5
60	4.4	21.3	4.6	20.2	—	11.6
70	—	21.8	—	18.6	3.6	16.8
80	—	—	—	—	—	17.2

Source: Stone, Earl L. *British yield tables for European and Japanese larches in New York.* Cornell Univ. Agron. Paper 397, 4 pp. 1957.

Table 19.—*Yield table for Norway spruce for site indexes 80 and 60*[1]

(In cords per acre)

Age (years)	Site index 80		Site index 60	
	Thinnings	Final cutting	Thinnings	Final cutting
20	—	13.3	—	—
30	10.5	44.1	—	18.9
40	15.6	68.5	7.8	36.5
50	13.0	76.0	12.2	59.2
60	17.3	90.6	19.2	74.2
70	—	105.6	—	83.3

Source: Marty, Robert J. *Office report on forest management possibilities on idle land in Potter County, Pennsylvania.* U. S. D. A. Forest Serv., NE. Forest Exp. Sta., Upper Darby, Pa., 1957.

Table 20.—*Yields per acre for hardwood stands that have been precommercially thinned, and for identical stands that have not been thinned, by site-productivity class*

Stand description	Age at time of precommercial thinning	Thinned stands				Yield from unthinned stands	
		Thinnings		Harvest			
		Age	Volume	Age	Volume	Age	Volume
	Years	*Years*	*M bd. ft.*	*Years*	*M bd. ft.*	*Years*	*M bd. ft.*
Northern hardwoods:							
Site I	40	70	5.9	80	17.7	90	23.6
Site II	40	70	4.5	80	13.4	90	17.9
Oak stands:							
Site I	40	80	5.2	90	15.6	100	20.8
Site II	40	80	2.6	90	7.7	100	10.3
Site III	40	—	—	90	1.5	100	1.5
Cove hardwoods:							
Site I	30	60	8.6	70	25.7	80	34.3
Site II	30	60	4.3	70	12.8	80	17.9

Source: Yields are based on data developed by Webster *(1960)*.

Table 21.—*Yields per acre for managed hardwood stands that have been cleaned and liberated at age 10-15 and will be subsequently thinned, and for identical unmanaged stands, by site productivity class*

Stand description	Yields from managed stands[1]				Yield from unmanaged stands[1]	
	Thinnings		Harvest			
	Years	*M bd. ft.*	*Years*	*M bd. ft.*	*Years*	*M bd. ft.*
Northern hardwoods:						
Site I	60	6.1	70	18.4	90	23.6
Site II	60	4.6	70	18.4	90	17.9
Oak:						
Site I	70	5.4	80	16.2	100	20.8
Site II	70	2.7	80	8.2	100	10.3
Site III	—	—	80	1.6	100	1.5

[1] Managed stands are stands that have been subjected to cleaning and liberation cuttings and will be subsequently thinned. In unmanaged stands, no cultural treatment will be undertaken.

Source: Yields are based on data developed by Webster *(1960)*.

FINANCIAL YIELD TABLES

Table 22.—*Financial yields of white pine plantations grown for sawlogs to the financially optimum rotation age for public establishment costs under high- and low-stumpage value assumptions, by site-productivity class*

(In percent, compound interest)

Investment		High price[1]			Low price[2]		
Source	Dollars per acre	Site I, 50-year rotation	Site II, 60-year rotation	Site III, 80-year rotation	Site I, 50-year rotation	Site II, 60-year rotation	Site III, 100-year rotation
		PLANTING ONLY					
ACP-CFM:							
Public	34.43	8.2	7.0	3.9	6.9	5.8	3.1
Private	4.28	12.9	10.8	6.5	11.5	9.6	6.2
Total	38.71	7.9	6.8	3.8	6.6	5.6	3.0
CFM:							
Public	18.17	9.6	8.1	4.8	8.3	7.0	3.8
Private	26.16	8.8	7.5	4.3	7.5	6.3	3.4
Total	44.33	7.6	6.8	3.6	6.3	5.4	2.9
		PLANTING AND SITE PREPARATION					
ACP-CFM:							
Public	49.34	7.4	6.3	3.5	6.1	5.2	2.8
Private	6.31	12.0	10.1	6.2	10.1	9.8	4.9
Total	55.65	7.1	6.1	3.3	5.8	5.0	2.6
CFM:							
Public	24.50	8.9	7.6	4.4	7.6	6.5	3.5
Private	35.15	8.1	6.7	3.9	6.8	5.8	3.1
Total	59.65	7.0	6.0	3.2	5.7	4.9	2.6
		PLANTING AND FENCING					
ACP-CFM:							
Public	44.43	7.6	6.5	3.6	6.3	5.4	2.9
Private	5.08	12.3	10.5	6.4	10.9	9.7	5.5
Total	49.51	7.4	6.3	3.5	6.1	5.2	2.8
CFM:							
Public	26.84	8.8	7.5	4.3	7.5	6.3	3.4
Private	37.36	8.0	6.9	3.8	6.7	5.7	3.0
Total	64.20	6.8	5.9	3.1	5.3	4.7	2.5
		PLANTING, SITE PREPARATION, AND FENCING					
ACP-CFM:							
Public	59.34	7.0	6.0	3.2	5.7	5.4	2.6
Private	7.11	11.9	10.0	6.0	9.8	8.8	4.8
Total	66.45	6.7	5.8	3.1	6.1	4.7	2.4
CFM:							
Public	33.17	8.2	7.0	4.0	6.9	5.9	3.0
Private	46.35	7.5	6.4	3.6	6.2	5.3	2.9
Total	79.52	6.4	5.0	2.9	5.0	4.3	2.3

[1] The high-stumpage value assumption is that the current market price is $43.95 per thousand board feet, and that it will increase at a rate of 1.1 percent per year over the length of the rotation.

[2] The low-stumpage price is $30.00 per thousand board feet, with an annual increase of 0.50 percent.

Table 23.—*Financial yields for red pine plantations grown for sawlogs to the financially optimum rotation age of 65 years for public establishment costs under high- and low-stumpage value assumptions, by site-productivity class*[1]

(In percent, compound interest)

Investment		High price[2]			Low price[3]		
Source	Dollars per acre	Site I	Site II	Site III	Site I	Site II	Site III
			PLANTING ONLY				
ACP-CFM:							
Public	34.43	8.3	7.6	6.9	7.3	6.7	6.1
Private	4.28	14.1	13.2	11.6	12.8	11.9	10.6
Total	38.71	8.0	7.4	6.8	7.1	6.5	5.9
CFM:							
Public	18.17	9.9	9.2	8.2	8.9	8.2	7.4
Private	26.16	9.0	8.3	7.5	8.0	7.3	6.6
Total	44.33	7.7	7.1	6.2	6.7	6.2	5.6
			PLANTING AND SITE PREPARATION				
ACP-CFM:							
Public	49.34	7.4	6.8	6.1	6.5	5.9	5.3
Private	6.31	12.9	12.0	10.4	11.7	10.9	9.6
Total	55.65	7.2	6.5	5.9	6.2	5.7	5.1
CFM:							
Public	24.50	9.2	8.5	7.5	8.1	7.5	6.7
Private	35.15	8.3	7.6	6.8	7.3	6.7	6.0
Total	59.65	7.0	6.4	5.7	6.1	5.5	4.9
			PLANTING AND FENCING				
ACP-CFM:							
Public	44.43	7.7	7.1	6.2	6.7	6.2	5.6
Private	5.08	13.4	12.5	12.3	12.0	11.4	10.0
Total	49.51	7.4	6.8	6.1	6.5	5.9	5.3
CFM:							
Public	26.84	9.0	8.3	7.5	8.0	7.3	6.6
Private	37.36	8.2	7.5	6.8	7.2	6.6	6.0
Total	64.20	6.5	6.2	5.8	5.9	5.3	4.7
			PLANTING, SITE PREPARATION, AND FENCING				
ACP-CFM:							
Public	59.34	7.7	6.4	5.7	6.1	5.5	4.9
Private	7.11	12.5	12.3	9.9	11.4	10.6	9.3
Total	66.45	7.4	6.1	5.5	5.8	5.3	5.3
CFM:							
Public	33.17	8.3	7.7	6.9	7.4	6.8	6.1
Private	46.35	7.6	7.0	6.1	6.6	6.0	5.4
Total	79.52	6.4	5.8	5.1	5.4	4.9	4.4

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[1] The 55-year rotation is optimum for all site-productivity classes and for both price assumptions.

[2] The high-stumpage value assumption is that current average market prices are $43.90 per thousand board feet and $5.50 per cord. Sawtimber prices are assumed to increase at 1.1 percent per year and pulpwood prices at 0.5 percent per year over the length of the rotation.

[3] Low- stumpage prices are $30.00 per thousand board feet and $3.50 per cord. Expected price increases are the same as for the high-value stumpage assumption.

Table 24.—*Financial yields for larch plantations grown for sawlogs to the financially optimum rotation age for public establishment costs under high- and low-stumpage value assumptions, by site-productivity class*

(In percent, compound interest)

Investment		High price[1]			Low price[2]		
Source	Dollars per acre	Site I, 40-year rotation	Site II, 40-year rotation	Site III, 60-year rotation	Site I, 40-year rotation	Site II, 40-year rotation	Site III, 60-year rotation
PLANTING ONLY							
ACP-CFM:							
Public	34.43	9.4	7.7	5.9	8.9	7.3	5.6
Private	4.28	16.0	13.7	9.9	15.5	13.2	9.6
Total	38.71	9.0	7.4	5.7	8.6	7.0	5.4
CFM:							
Public	18.17	11.4	9.5	7.1	10.9	9.1	6.8
Private	26.16	10.2	8.5	6.4	9.7	8.1	6.1
Total	44.33	8.6	7.1	5.4	8.2	6.6	5.1
PLANTING AND SITE PREPARATION							
ACP-CFM:							
Public	49.34	8.3	6.8	4.9	7.8	6.3	4.9
Private	6.31	14.7	12.5	9.1	14.2	12.1	8.8
Total	55.65	7.9	6.4	5.0	7.5	6.0	4.7
CFM:							
Public	24.50	10.4	8.7	6.5	10.0	8.3	6.2
Private	35.15	9.0	7.7	5.9	8.9	7.3	5.6
Total	59.65	7.7	6.2	4.9	7.3	5.8	4.6
PLANTING AND FENCING							
ACP-CFM:							
Public	44.43	8.6	7.1	5.4	8.2	6.6	5.1
Private	5.08	15.2	13.2	9.6	15.0	12.8	9.3
Total	49.51	8.3	6.8	4.9	7.8	6.3	4.9
CFM:							
Public	26.84	10.2	8.5	6.4	9.7	8.1	6.1
Private	37.36	9.0	7.7	5.8	8.9	7.3	5.5
Total	64.20	7.5	6.0	4.8	7.0	5.6	4.4
PLANTING, SITE PREPARATION, AND FENCING							
ACP-CFM:							
Public	59.34	7.7	6.2	4.9	8.2	5.8	4.6
Private	7.11	14.3	12.2	8.9	13.8	11.7	8.6
Total	66.45	7.4	5.9	4.7	7.8	5.5	4.4
CFM:							
Public	33.17	9.4	7.8	5.9	9.0	7.3	5.6
Private	46.35	8.3	6.9	5.2	8.1	6.5	5.0
Total	79.52	6.8	5.5	4.4	6.5	5.1	4.1

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[1] The high-stumpage value assumption is that the current market price is $35.00 per thousand board feet and that it will increase at a rate of 1.1 percent per year over the length of the rotation.

[2] The low-stumpage price assumption is $30.00 per thousand board feet, with an annual increase of 1.1 percent per year.

Table 25.—Financial yields of Norway spruce plantations grown for pulpwood to the financially optimum rotation age for public establishment costs under high- and low-stumpage value assumptions, by site-productivity class.

(In percent, compound interest)

Investment		High price[1]		Low price[2]	
Source	Dollars per acre	Site I, 30-year rotation	Site II, 50-year rotation	Site I, 40-year rotation	Site II, 50-year rotation
PLANTING ONLY					
ACP-CFM:					
Public	34.43	9.0	6.5	7.8	5.8
Private	4.28	17.1	11.3	14.1	10.6
Total	38.71	8.6	6.2	7.4	5.5
CFM:					
Public	18.17	11.4	7.9	9.7	7.2
Private	26.16	10.0	7.1	8.6	6.4
Total	44.33	8.0	5.9	7.0	5.2
PLANTING AND SITE PREPARATION					
ACP-CFM:					
Public	49.34	7.7	5.7	6.7	5.0
Private	6.31	15.6	10.4	12.9	9.7
Total	55.65	7.2	5.4	6.4	4.7
CFM:					
Public	24.50	10.3	7.2	8.8	6.5
Private	35.15	8.9	6.4	7.7	5.7
Total	59.65	6.9	5.2	6.2	4.5
PLANTING AND FENCING					
ACP-CFM:					
Public	44.43	8.0	5.9	7.0	5.2
Private	5.08	16.2	10.7	13.4	10.0
Total	49.51	7.7	5.7	6.7	5.0
CFM:					
Public	26.84	10.0	7.1	8.6	6.4
Private	37.36	9.0	6.4	7.7	5.7
Total	64.20	6.6	5.0	5.9	4.3
PLANTING, SITE PREPARATION, AND FENCING					
ACP-CFM:					
Public	59.34	6.9	5.2	6.2	4.5
Private	7.11	15.1	10.1	12.4	9.4
Total	66.45	6.0	5.0	5.9	4.3
CFM:					
Public	33.17	9.1	6.5	7.8	5.8
Private	46.35	8.0	5.9	6.9	5.1
Total	79.52	5.9	4.6	5.4	4.0

[1] The high-stumpage value assumption is that the current market price is $7.50 per cord and that it will increase at a rate of 1.1 percent per year over the length of the rotation.

[2] The low-stumpage price is $5.50 per cord, with an annual increase of 1.1 percent.

Table 26.—*Financial yield to investments in cleaning and cull-tree removal in oak and northern hardwood stands, by site-productivity class*
(In percent, compound interest)

Investment				
Source	Dollars per acre	Site I	Site II	Site III
	OAK STANDS			
ACP-CFM:				
Public	33.29	5.4	4.1	1.0
Private	6.95	8.3	7.1	3.2
Total	40.24	5.1	3.7	1.0
ACP-CFM:				
Public	12.94	7.2	5.9	1.6
Private	25.00	6.0	4.7	1.0
Total	37.94	5.2	3.9	1.0
	NORTHERN HARDWOODS			
ACP-CFM:				
Public	33.29	7.3	6.3	—
Private	6.95	10.3	9.7	—
Total	40.24	7.0	5.9	—
CFM:				
Public	12.94	9.2	8.4	—
Private	25.00	7.9	7.0	—
Total	37.94	6.7	6.1	—

Table 27.—*Financial yield to investments in precommercial thinning in oak, northern hardwoods, and cove hardwood stands, by site-productivity class*

(In percent, compound interest)

Investment				
Source	Dollars per acre	Site I	Site II	Site III
	OAK STANDS			
ACP-CFM:				
Public	33.29	7.9	6.0	1.0
Private	6.95	12.1	10.2	4.4
Total	40.24	7.4	5.4	1.0
CFM:				
Public	12.94	10.4	1.0	2.7
Private	25.00	8.6	11.8	1.0
Total	37.94	7.5	5.6	1.0
	NORTHERN HARDWOODS			
ACP-CFM:				
Public	33.29	11.1	10.2	—
Private	6.95	16.7	15.7	—
Total	40.24	10.5	9.5	—
CFM:				
Public	12.94	14.5	13.5	—
Private	25.00	12.1	11.2	—
Total	37.94	10.7	9.7	—
	COVE HARDWOODS			
ACP-CFM:				
Public	33.29	12.4	9.9	—
Private	6.95	18.0	15.5	—
Total	40.24	11.7	9.2	—
CFM:				
Public	12.94	15.8	13.3	—
Private	25.00	13.4	10.9	—
Total	37.94	11.9	9.4	—

Table 28.—*Average public, private, and total costs for individual practice accomplishments under ACP-CFM and CFM*

(In dollars per acre)

Practice	Public costs	Private costs	Total costs
ACP-CFM-SUPPORTED			
Planting practices:			
Planting	$34.43	$ 4.28	$38.71
Site preparation	14.91	2.03	16.94
Fencing plantations	10.00	.80	10.80
Timber stand improvement	33.29	6.95	40.24
Pruning	22.81	2.68	25.49
Fencing natural stands	14.19	.82	15.01
Total ACP-CFM	29.81	4.49	34.30
CFM-SUPPORTED			
Planting practices:			
Planting	18.17	26.16	44.33
Site preparation	6.33	8.99	15.32
Fencing	8.67	11.20	19.87
Timber stand improvement	12.94	25.00	37.94
Fencing natural stands	13.63	3.59	17.22
Total CFM	15.38	22.23	37.61
Harvesting assistance	12.11	—	12.11
Total CFM	13.71	22.23	24.56
Total ACP-CFM and CFM	$23.52	$ 8.72	$30.50

Table 29.—*Rates of interest calculated on total investments in ACP-CFM and CFM practices, by site-productivity class*

(In percent, compound interest)

Practice	Site I	Site II	Site III
ACP-CFM-SUPPORTED			
Planting:[1]			
White pine	7.9	6.8	3.8
Red pine	8.0	7.4	6.8
Larch	9.0	7.4	5.7
Norway spruce	8.6	6.2	[2]
Cleaning and liberation:			
Oak	5.1	3.7	1.0
Northern hardwoods	7.0	5.9	[2]
Thinning:			
Oak	7.4	5.4	1.0
Northern hardwoods	10.5	9.5	[2]
Cove hardwoods	11.7	9.2	[2]
CFM-SUPPORTED			
Planting:[1]			
White pine	7.6	6.5	3.6
Red pine	7.7	7.1	6.2
Larch	8.5	7.1	5.4
Norway spruce	8.0	5.9	[2]
Cleaning and liberation:			
Oak	5.2	3.9	1.0
Northern hardwoods	6.7	6.1	[2]
Thinning:			
Oak	7.5	5.6	1.0
Northern hardwoods	10.7	9.7	[2]
Cove hardwoods	11.9	9.4	[2]

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[1] Returns for planting are returns earned under the higher of the two stumpage price assumptions employed in the calculations.

[2] Physical yield data not available for site-productivity class III.

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The "LET-IT-GROW" Treatment for timber —is it economically worthwhile?

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ONE WAY TO TREAT a timber stand is to ignore it—simply let it grow. This treatment will in time produce usable timber. And this is how many small woodlands in the Northeast are treated today. The question is: How well does this treatment work in returning a profit to the owner?

As a guide for forest managers, the Northeastern Forest Experiment Station has made an economic study of this let-it-grow treatment. We found that the profitability of this treatment depends mainly upon the age of the stand and the timber markets available.

Our analyses suggest that the forest manager should consider other ways to treat his timber. This report was prepared to provide a yardstick against which the manager can measure other management options to help him decide, for different situations, what treatment will be most profitable.

An economic evaluation is usually made for a specific time period. Long-run evaluations usually start with bare ground at the beginning of a rotation. However, private woodlands usually have a forest stand of some sort already on the ground, so evaluations beginning at different stages of forest development might be more meaningful than those beginning with little or no timber. And because the tenure of most woodland owners is less than 20 years, it is clear that for most owners a rotation is too long a period on which to base an evaluation. Five, 10, or 15 years may be a more useful time horizon.

Our economic evaluation of the let-it-grow option is based on a 10-year period. It is built around several different analyses, and is presented as an array of the economic consequences of the let-timber-grow decision.

The economic measures used as a basis for evaluation include volume and value increments per acre and rates of return to the standing timber investment. Reasonable management goals are developed for each of these measures, and the evaluation is conducted by contrasting stand performance to management goals. Information from different economic points of view is thus provided to help forest land managers sharpen their judgment.

Even-aged fully stocked upland oak stands 20, 40, 60, 80, 100, and 120 years old growing on site indexes of 40, 60, and 80 are the forest situations evaluated. Timber values that depend on a single market, on changing markets, and on multiple markets are considered.

The Physical Basis

Stand tables for upland oak sites 40, 60, and 80 (from *Schnur 1937*) were used as a beginning. These tables, based on empirical data, take into account species compositions, and extend to 100 years. Most of these stands followed charcoal-wood operations in which stands were clearcut to 2 or 3 inches d.b.h. This is essentially the management procedure recommended by foresters today for hardwood stands to be used mainly for timber production.

Stand tables for site indexes 40 and 80 were extended to 120 years, while the stand table for site index 60 was extended to 130 years. The proportion of the trees living from ages 90 to 100 years was held constant in the extension. This amounted to between

90 to 95 percent of the trees at the beginning of each 10-year period. Living trees were moved to successive diameter classes during the 10-year period by the movement-factor method (*Meyer 1953*). This factor varied from 0.50 to 0.75, and the numbers of trees were rounded off to the nearest tree to conform to the original tables. Stand tables to 100 years appear in Schnur's well-known work (*Schnur 1937*), and the extensions are shown in table 1.

Table 1. — Stand-table extensions for selected sites and ages

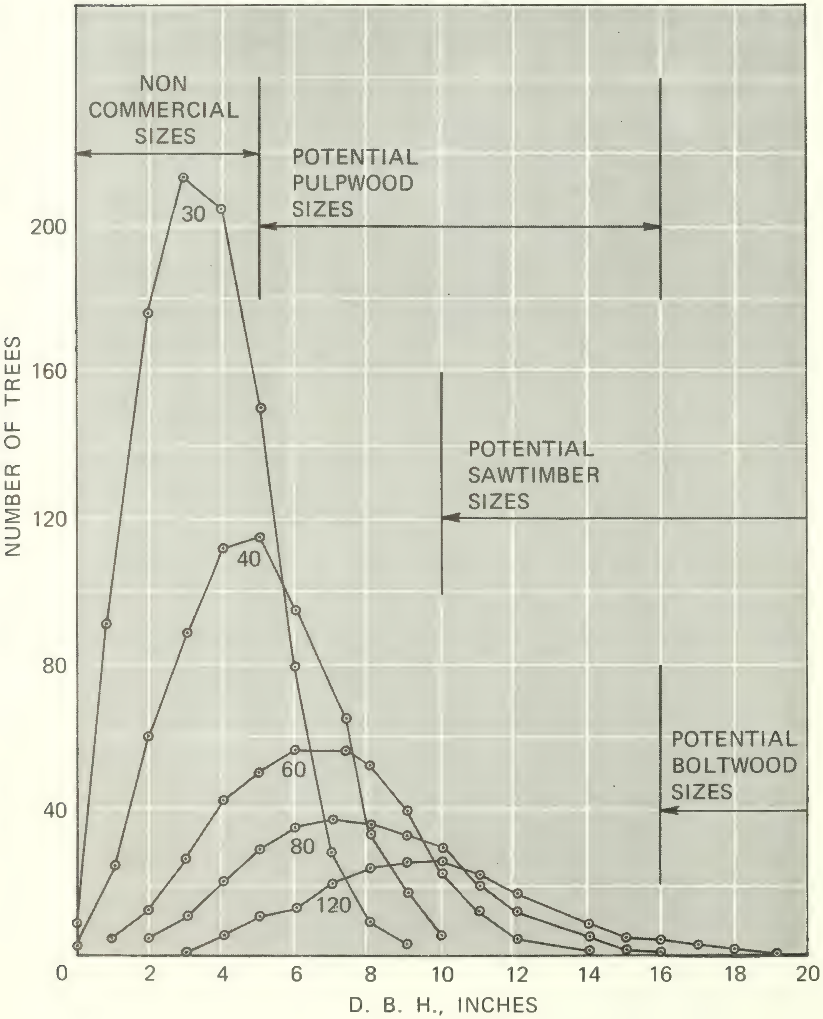
[Number of trees per acre]

D.b.h. (inches)	Stand age						
	110			120			130
	SI 40	SI 60	SI 80	SI 40	SI 60	SI 80	SI 60
0	—	—	—	—	—	—	—
1	3	—	—	1	—	—	—
2	9	—	—	7	—	—	—
3	22	4	—	15	2	—	—
4	34	9	3	25	6	1	6
5	49	13	3	39	12	3	9
6	54	20	7	47	14	5	11
7	56	24	9	50	20	6	15
8	52	28	9	49	24	8	22
9	39	27	12	41	26	9	23
10	27	25	11	30	23	11	21
11	17	22	11	20	22	10	18
12	10	16	11	12	17	9	16
13	3	16	11	6	14	11	14
14	2	9	12	3	10	11	10
15	1	6	9	1	6	10	8
16	—	5	7	1	5	7	5
17	—	3	6	—	5	5	5
18	—	1	6	—	1	6	3
19	—	—	3	—	1	5	1
20	—	—	2	—	—	3	1
21	—	—	2	—	—	2	—
22	—	—	1	—	—	1	—
23	—	—	1	—	—	1	—
24	—	—	—	—	—	1	—

The development of tree-size distributions is illustrated in figure 1 for site index 60 stands. Though species compositions are not shown in either table 1 or figure 1, they were used in the subsequent analyses.

Tree size limits the variety of wood products that can be made from a tree or stand. This is emphasized in figure 1. Pulpwood is

Figure 1. — Tree-size distributions for selected hardwood stand ages growing on site index 60 land.



the main product that younger stands—say age 40—can be expected to produce. Older timber stands can be used for other products in addition to pulpwood, and for combinations of products.

We are concerned only with the trees in the original stand and not with trees that might seed in later during the life of the stand. This limitation is not severe because, with fully stocked forest stands as dense as those studied, there will be little opportunity for seedlings to become established. Recent forest-survey reports for states in the oak region indicate that 40 to 50 percent of the commercial forest area has over 70 percent of full stocking. The quantitative results of this study may be directly applicable to many of these stands.

Stand volumes were estimated by multiplying the numbers of trees in each diameter class by the volumes for that class from an appropriate volume table. Board-foot volumes are based on the International 1/4-inch rule to an 8-inch top. Standard volume tables were localized by using Schnur's height-diameter curves as a basis for selecting proper tree volumes. The stand volumes resulting from this procedure are shown in table 2.

Table 2. — Decadal yield table for selected sites

[Stand volumes in board feet, International ¼-inch rule]

Age (years)	Stand volumes		
	SI 40	SI 60	SI 80
20	—	—	—
30	—	—	490
40	—	258	3,645
50	—	2,130	8,270
60	245	4,208	11,915
70	652	6,433	14,290
80	1,287	8,447	16,075
90	2,564	10,767	17,490
100	3,720	12,020	18,915
110	5,265	13,518	20,415
120	6,952	14,541	21,860
130	—	15,454	—

The validity of the evaluation depends on how reasonable these synthesized volumes are; so they were compared with independent data in the files of the Northeastern Forest Experiment Station.[1] The results of this comparison are shown in figure 2, in which the synthesized volumes for site index 60 are compared with the empirical data for site indexes 55 and 65. The minimum merchantable diameter of 8 inches in the synthesized work should give higher volumes than the empirical curves, which are based on a minimum merchantable diameter of 10 inches. The quantitative differences in figure 2 exhibit this relation, and the curve inflections are similar; so the synthesized data were judged satisfactory. The synthesized volumes were used for all lumber and bolt products.

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[1] The author thanks Samuel F. Gingrich, mensurationist, Northeastern Forest Experiment Station, for guiding these reasonability checks.

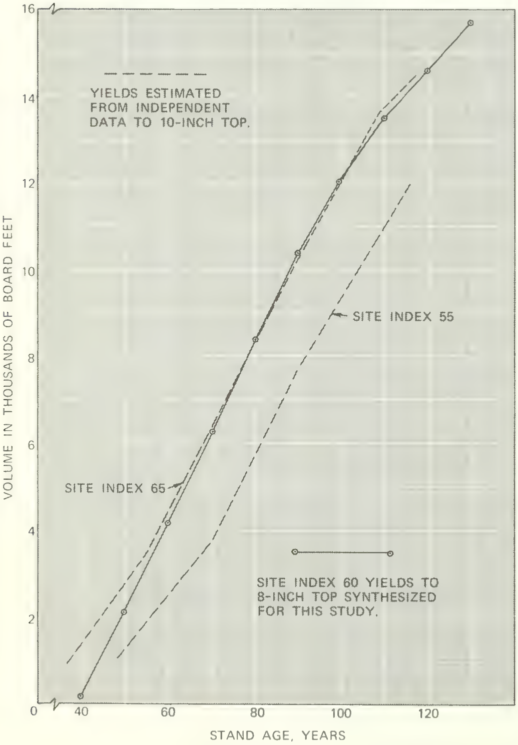

Figure 2. — Total product curve, in board feet, International ¼-inch rule, for site index 60 compared to independent checks.

Pulpwood volumes were calculated in the same manner, but were restricted to trees 5 to 16 inches d.b.h. When more than one wood product was considered, the multi-product principles and ratios adapted from Worley (*1958, 1963*) were used to prorate volumes to different products.

The Value Basis

Current stumpage values from Ohio, Kentucky, and Indiana price and market reports were used as a value basis. Unit values for pulpwood, sawtimber, and boltwood were developed to assess the importance of product alternatives to the economics of managing these stands. Since Schnur did not recognize tree quality in his work, certain quality assumptions were made, based on the work of Trimble (*1965*), who showed that tree quality increases with tree size. Since definitive information is lacking about the proportion of timber suitable for boltwood products, it was assumed that 50 percent of the volumes of trees that had logs with scaling diameters of 18 inches or larger were suitable for veneer, and that 50 percent of the volume of white oaks having a 16-inch d.b.h. could be included as stave-billet material in this market. Pulpwood is considered an alternative only for trees 16 inches d.b.h. and smaller.

Inspection of the price reports in light of these assumptions suggested a price schedule as follows:

Product used as a basis of value	*Minimum tree diameter specifications (inches d.b.h.)*	*Unit*	*Price (dollars)*
Pulpwood	All trees 5-16 inches	Cord	2.00
Sawtimber	Trees 10-12 inches	M ft. b.m.	10.00
	Trees 13-17 inches	M ft. b.m.	20.00
	Trees 18+ inches	M ft. b.m.	30.00
Stave bolts	White oak trees 16+ inches	M ft. b.m.	100.00
Other bolts	All trees 18+ inches	M ft. b.m.	100.00

In addition to a price schedule, a limit is needed on minimum merchantable quantities that operators ordinarily accept. For our purposes a minimum of 5 cords of pulpwood, or 2,500 board feet of sawtimber, or 500 board feet of boltwood products per acre must be present for operability. We would use these limits then to say that a stand that has developed to the point where it contained 10 cords of pulpwood or 2,000 board feet of sawtimber would be valued only for pulpwood but not for sawtimber at that time. In 10 years, when it would contain say 18 cords of pulpwood and 3,500 board feet of sawtimber, it would be operable for either or both. When these values and market rules are applied to the physical data cited earlier, an array of values is produced at any particular age, as shown for site index 60 in figure 3.

Above age 60, stands have at least three values, depending upon the market context used. The dashed connecting lines (fig. 3) illustrate the lumpy nature of the total-value curve in the presence of all markets. Expanding market potential through either the introduction of new markets or the eligibility of the timber for higher valued products through increasing size, can have a dramatic effect on the desirability of a forest investment.

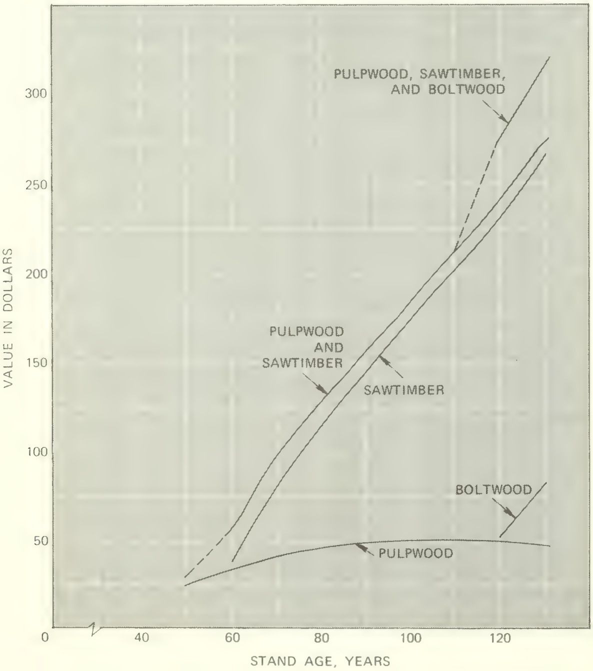

Figure 3. — Total-value curves, showing effects of individual products and potential product mixes on value for SI 60 stands.

Analysis of Volume and Volume Increments for Selected 10-Year Periods

Physical product data were converted to volumes of commercial products (table 3), using the rules cited earlier. Table 3 shows that forest stands growing on good sites produce merchantable volumes very quickly, and that the spectrum of product alternatives is greatest for older stands on good sites.

Sawtimber is divided (table 3) into three classes based on size and potential quality. Class 1 represents small and generally low-quality timber; class 2 medium-size medium-quality timber; and class 3 large and generally high-quality timber. Although volume increments (sum of board feet for classes 1, 2, and 3) for ages 80 and 100 are very nearly the same for all three sites, the major differences are in the products produced. At these ages the greatest contribution to board-foot volume growth on poorer sites is made by ingrowth trees represented in class 1 while on the better sites most board-foot volume growth is put on larger and potentially more valuable trees specified as class 3.

For our purposes though, an analysis should show (1) whether the timber is marketable for particular products and (2) whether it is meeting reasonable production goals. The first indicates whether or not the forest manager has the option to cut available to him and the second sets up reasonable production goals against which he can exercise his option to cut it or let it grow. The merchantability quantities cited earlier (5 cords of pulpwood, 2,500 board feet of sawtimber, or 500 board feet of boltwood) suffice for the first part of the analysis. Acceptable production goals for a decade may be 5 cords per acre of pulpwood, 1,000 board feet of sawtimber, and 250 board feet of boltwood. Table 4 summarizes our estimated stand performance against these standards.

Table 4 shows that the option to cut is open for one product or another for all stands 60 years and older. Whether or not

Table 3. — Estimated volumes per acre of commercial products at selected ages and volume increments for 10 years

Age (years)	Timber product[1]		Beginning volumes			10-year increments		
			SI 40	SI 60	SI 80	SI 40	SI 60	SI 80
20	Cords		—	—	5.1	.8	4.7	7.9
	Logs, board feet	1	—	—	—	—	—	490
	” ”	2	—	—	—	—	—	—
	” ”	3	—	—	—	—	—	—
	Bolts, board feet		—	—	—	—	—	—
40	Cords		2.5	9.2	20.6	1.5	4.6	7.9
	Logs, board feet	1	—	258	3,315	—	1,760	2,530
	” ”	2	—	—	330	—	112	2,095
	” ”	3	—	—	—	—	—	—
	Bolts, board feet		—	—	—	—	—	—
60	Cords		5.6	17.3	31.1	1.2	3.5	—0.4
	Logs, board feet	1	245	3,717	6,085	407	1,113	—905
	” ”	2	—	491	5,830	—	1,112	2,560
	” ”	3	—	—	—	—	—	720
	Bolts, board feet		—	—	—	—	—	360
80	Cords		8.0	23.8	30.3	1.7	2.0	—1.6
	Logs, board feet	1	1,189	5,779	4,545	1,158	1,079	—555
	” ”	2	98	2,668	9,920	119	1,241	500
	” ”	3	—	—	1,610	—	—	1,470
	Bolts, board feet		—	—	950	—	—	880

100......	Cords		11.0	27.0	27.5	1.6	—1.0	—2.0
	Logs, board feet	1	3.220	6,522	3,515	1,250	—100	—380
	” ”	2	500	5,498	10,410	295	1,347	—100
	” ”	3	—	—	4,990	—	251	1,980
	Bolts, board feet		—	—	2,820	—	238	1,190
120......	Cords		14.0	25.2	23.8	—	—0.8	—
	Logs, board feet	1	5,414	6,498	2,820	—	—584	—
	” ”	2	1,538	7,441	10,380	—	549	—
	” ”	3	—	602	8,660	—	948	—
	Bolts, board feet		—	541	5,040	—	474	—

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[1] Board-foot log products include cordwood from trees over 10 inches d.b.h. and boltwood products. Board-foot log products (1) from small trees, (2) from medium trees, and (3) from large trees then are additive.

Table 4. — The occurrence of merchantability and production alternatives for selected ages and sites of hardwood stands

Age (years)	Site index 40						Site index 60						Site index 80					
	Pulp-wood		Saw-timber		Bolt-wood		Pulp-wood		Saw-timber		Bolt-wood		Pulp-wood		Saw-timber		Bolt-wood	
	M	*P*[1]	*M*	*P*	*M*	*P*	*M*	*P*	*M*	*P*	*M*	*P*	*M*	*P*	*M*	*P*	*M*	*P*
20	0	0	0	0	0	0	0	0	0	0	0	0	+	+	0	0	0	0
40	0	0	0	0	0	0	+	0	0	+	0	0	+	+	+	+	0	0
60	+	0	0	0	0	0	+	0	+	+	0	0	+	0	+	+	+	+
80	+	0	+	0	0	0	+	0	+	+	0	0	+	0	+	+	+	+
100	+	0	+	+	0	0	+	0	+	+	0	0	+	0	+	+	+	+
120	—	—	—	—	—	—	+	0	+	+	+	+	—	—	—	—	—	—

[1] + in the *M* (merchantable) column indicates the option to cut for that product is open. + in the *P* (production) column indicates that stand growth equals or exceeds growth criteria.

production goals are met depends upon the product, stand age, and site quality. Pulpwood production goals are made only by young stands on high sites. Sawtimber goals are met by stands 40 years and older on medium and high sites. Meeting boltwood goals requires older stands on the better sites. Table 4 forms a production-goal framework for deciding what to do in a single stand-site-market situation. Presumably, if the production goal is not met, and the stand is merchantable, the stand should be cut according to this yardstick.

[illegible] 10-Year [illegible]

Value increments per acre may be a viable economic goal for many owners. Their reasoning may be: "I want to pay taxes, and/or other custodial charges, and/or return an average dollar rate per acre." This reasoning is worthwhile if they have other objectives for their timber holdings and want to add the benefits from several uses for additional economic evaluations, or if they are speculating on other values as land value and want assurances that timber alone will carry the out-of-pocket investment costs.

The value analysis began by multiplying the product volumes in table 4 by the appropriate values cited in the value-basis section. The estimated value and value increments appear in table 5.

It is evident (table 5) that market potential, present and prospective, plays a controlling role in the development of timber value. For our 60-year-old, site-index 60 stand, for example, the introduction of a pulpwood market, where only a sawtimber market existed before, increases the value increment from $44 to $60, a positive change of 36 percent. A positive market change can occur in two ways: (1) a new wood-using industry that requires a previously unmerchantable round-wood product as its raw material becomes established in an area; or (2) the timber stand develops to the point where it produces merchantable

Table 5. — Estimated per-acre values and 10-year value increments for timber of selected ages and markets, in dollars

Age (years)	Present market as basis for valuation		Present value per acre	Ten-year per-acre value increments for selected future markets[1]				
				(1)	(2)	(3)	(4)	(5)
			SITE INDEX 40					
20	Pulpwood	(1)	—	—	—	—	—	—
40	Pulpwood	(1)	—	—	—	—	—	—
	Sawtimber	(2)	—	—	—	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	—	—
60	Pulpwood	(1)	11	2	—	—	—	—
	Sawtimber	(2)	—	—	—	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	—	—
80	Pulpwood[2]	(1)	16	3	15	24	—	—
	Sawtimber	(2)	—	—	—	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	—	—
	Pulp., saw., & bolt.	(4)	—	—	—	—	—	—
	Boltwood	(5)	—	—	—	—	—	—
100	Pulpwood	(1)	22	3	39	51	—	—
	Sawtimber	(2)	42	—	19	31	—	—
	Pulpwood & sawtimber	(3)	55	—	—	18	—	—
	Pulp., saw., & bolt.	(4)	—	—	—	—	—	—
	Boltwood	(5)	—	—	—	—	—	—
120	Pulpwood	(1)	28	—	—	—	—	—
	Sawtimber	(2)	85	—	—	—	—	—
	Pulpwood & sawtimber	(3)	94	—	—	—	—	—
	Pulp., saw., & bolt.	(4)	—	—	—	—	—	—
	Boltwood	(5)	—	—	—	—	—	—

SITE INDEX 60

20......	Pulpwood	(1)	—	—	—	—	—	—
40......	Pulpwood	(1)	18	9	—	—	—	—
	Sawtimber	(2)	—	—	—	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	—	—
60......	Pulpwood	(1)	35	7	46	62	—	—
	Sawtimber	(2)	37	—	44	60	—	—
	Pulpwood & sawtimber	(3)	57	—	—	40	—	—
80......	Pulpwood[2]	(1)	48	4	103	116	—	—
	Sawtimber	(2)	111	—	36	49	—	—
	Pulpwood & sawtimber	(3)	126	—	—	34	—	—
	Pulp., saw., & bolt.	(4)	—	—	—	—	—	—
	Boltwood	(5)	—	—	—	—	—	—
100......	Pulpwood	(1)	54	—	155	165	—	—
	Sawtimber	(2)	175	—	34	44	—	—
	Pulpwood & sawtimber	(3)	186	—	—	33	—	—
	Pulp., saw., & bolt.	(4)	—	—	—	—	—	—
	Boltwood	(5)	—	—	—	—	—	—
120......	Pulpwood	(1)	50	—	215	224	294	—
	Sawtimber	(2)	232	—	33	42	112	—
	Pulpwood & sawtimber	(3)	241	—	—	33	103	—
	Pulp., saw., & bolt.	(4)	277	—	—	—	67	—
	Boltwood	(5)	54	—	—	—	—	47

SITE INDEX 80

20......	Pulpwood	(1)	10	16	—	—	—	—
40......	Pulpwood	(1)	41	16	63	83	—	—
	Sawtimber	(2)	33	—	71	91	—	—
	Pulpwood & sawtimber	(3)	58	—	—	66	—	—

CONTINUED

Table 5. — Continued

Age (years)	Present market as basis for valuation		Present value per acre	Ten-year per-acre value increments for selected future markets[1]				
				(1)	(2)	(3)	(4)	(5)
60	Pulpwood	(1)	62	—	179	190	—	—
	Sawtimber	(2)	177	—	64	75	—	—
	Pulpwood & sawtimber	(3)	191	—	—	61	—	—
80	Pulpwood[2]	(1)	61	—	280	287	356	—
	Sawtimber	(2)	292	—	49	50	125	—
	Pulpwood & sawtimber	(3)	301	—	—	47	116	—
	Pulp., saw., & bolt.	(4)	348	—	—	—	69	—
	Boltwood	(5)	95	—	—	—	—	88
100	Pulpwood	(1)	55	—	392	397	589	—
	Sawtimber	(2)	393	—	54	59	251	—
	Pulpwood & sawtimber	(3)	399	—	—	53	245	—
	Pulp., saw., & bolt.	(4)	532	—	—	—	112	—
	Boltwood	(5)	282	—	—	—	—	119
120	Pulpwood	(1)	48	—	—	—	—	—
	Sawtimber	(2)	496	—	—	—	—	—
	Pulpwood & sawtimber	(3)	500	—	—	—	—	—
	Pulp., saw., & bolt.	(4)	744	—	—	—	—	—
	Boltwood	(5)	504	—	—	—	—	—

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[1] Numbers in parentheses correspond to markets in column 2.

[2] An 80-year-old stand on site 40 land now merchantable for pulpwood may be expected to add \$3.00, \$15.00, or \$25.00 in value in the next 10 years if the market then is for pulpwood, or sawtimber, or a combination of pulpwood and sawtimber, respectively, at that time.

quantities of a new wood product. A forest manager can speculate on market development in much the same way that stock, commodity, and real estate investors speculate on market changes for their products.

The performance standard or management goal used here for gaging the performances listed in table 5 is that the value increments must cover custodial costs and include additional cash returns. The costs of ownership are usually annual costs while the value increments in table 5 are for a decade. Our analysis needs to equate these in order to consider out-of-pocket costs realistically. This requires compounding annual costs at appropriate rates of interest for comparison with decadal value increments.

The formula for the future value of a terminable series of annual payments was used. It was altered to determine the value increment required to cover a series of annual costs.

$$V_i = a\left[\frac{(1+p)^n - 1}{p}\right]$$

Where V_i = Value increment.
a = Annual payments.
p = Interest rate.
n = Period of years: 10 years in our case.

We are asking, for example, the value increment to pay for say \$1.50 annual custodial charges at 4 percent in 10 years.

$$V_i = \$1.50\left[\frac{(1.48024) - 1}{0.04}\right] = \$18.00$$

Reference to table 6, which gives solutions to this equation for 4- and 6-percent interest rates, shows that a decadal value increment of \$18.00 (1 + 7 + 10 column 1) is equivalent to annual payments of \$1.49 (\$0.08 + \$0.58 + 0.83 column 2) for 10 years at 4-percent interest.

Table 6 can be used in two different ways. First, the annual costs covered by a value increase can be estimated for any given decadal value increment in table 5. Costs for one of the two interest rates are summed until they equal the estimated increment. For example, the 10-year sawtimber value increment for age 80

Table 6. — Decadal value increments required to pay for annual costs at 4- and 6-percent interest for a 10-year period[1]

Dollar decadal value increments (V_i)	Annual dollar cost (a)	
	p = 4 percent	p = 6 percent
1	0.08	0.07
2	.17	.15
4	.33	.31
7	.58	.53
10	.83	.76
20	1.66	1.51
40	3.33	3.03
70	5.84	5.31
100	8.33	7.59

[1] $V_i = a\left[\frac{(1+p)^n - 1}{p}\right]$

where V_i = value increments
a = annual cost
n = 10 years
p = interest rate

site index 80 is (from table 5) $49. The annual cost equivalent is obtained by adding individual annual costs (table 6) for decadal values of 40, 7, and 2. For 4 percent this amounts to $3.33 + 0.58 + 0.17 = $4.08 per year, and for 6 percent it amounts to $3.71 per year. If $3.50 per acre per year is judged to be an adequate return, this forest stand can be expected to make it during the next 10 years and can be let grow.

This procedure can be turned around so that, given a 4-percent annual value requirement of $3.50 as a goal, we can show what minimum decadal value increment is required. In this case $3.33 and $0.17 in the 4-percent annual column sum to $3.50 and are equivalent to 40 + 2 = $42.00 per decade value increment. Stands making less than this do not meet the goal and should be considered financially mature for cutting.

Taxes on forest land of $0.25 to $0.30 per acre are common. Total custodial charges including taxes of $0.50 to $0.75 per acre are often considered reasonable. These minimal annual charges, if they are to be met from timber growing, require decadal returns

Table 7. — The occurrence of stands meeting (A) $30 and (B) $100 per-acre-per-decade value performance standards

Age (years)	Present market as basis for valuation		Selected future markets[1]									
			(1)		(2)		(3)		(4)		(5)	
			A	B	A	B	A	B	A	B	A	B
			SITE INDEX 40									
20......	Pulpwood	(1)	—	—	—	—	—	—	—	—	—	—
40......	Pulpwood	(1)	—	—	—	—	—	—	—	—	—	—
	Sawtimber	(2)	—	—	—	—	—	—	—	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	—	—	—	—	—	—
60......	Pulpwood	(1)	O[2]	—	—	—	—	—	—	—	—	—
	Sawtimber	(2)	—	—	—	—	—	—	—	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	—	—	—	—	—	—
80......	Pulpwood	(1)	O	—	O	—	O	—	—	—	—	—
	Sawtimber	(2)	—	—	—	—	—	—	—	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	—	—	—	—	—	—
	Pulp., saw., & bolt.	(4)	—	—	—	—	—	—	—	—	—	—
	Boltwood	(5)	—	—	—	—	—	—	—	—	—	—
100......	Pulpwood	(1)	O	—	+	O	+	O	—	—	—	—
	Sawtimber	(2)	—	—	O	—	+	O	—	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	O	—	—	—	—	—
	Pulp., saw., & bolt.	(4)	—	—	—	—	—	—	—	—	—	—
	Boltwood	(5)	—	—	—	—	—	—	—	—	—	—

CONTINUED

Table 7. — Continued

Age (years)	Present market as basis for valuation		Selected future markets[1]									
			(1)		(2)		(3)		(4)		(5)	
			A	B	A	B	A	B	A	B	A	B
SITE INDEX 60												
20......	Pulpwood	(1)	—	—	—	—	—	—	—	—	—	—
40......	Pulpwood	(1)	O[2]	—	—	—	—	—	—	—	—	—
	Sawtimber	(2)	—	—	—	—	—	—	—	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	—	—	—	—	—	—
60......	Pulpwood	(1)	O	—	+	O	+	O	—	—	—	—
	Sawtimber	(2)	—	—	+	O	+	O	—	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	+	O	—	—	—	—
80......	Pulpwood	(1)	O	—	+	+	+	+	—	—	—	—
	Sawtimber	(2)	—	—	+	O	+	O	—	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	+	O	—	—	—	—
	Pulp., saw., & bolt.	(4)	—	—	—	—	—	—	—	—	—	—
	Boltwood	(5)	—	—	—	—	—	—	—	—	—	—
100.....	Pulpwood	(1)	—	—	+	+	+	+	—	—	—	—
	Sawtimber	(2)	—	—	+	O	+	O	—	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	+	O	—	—	—	—
	Pulp., saw., & bolt.	(4)	—	—	—	—	—	—	—	—	—	—
	Boltwood	(5)	—	—	—	—	—	—	—	—	—	—
120......	Pulpwood	(1)	—	—	+	+	+	+	+	+	—	—
	Sawtimber	(2)	—	—	+	O	+	O	+	+	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	+	O	+	+	—	—
	Pulp., saw., & bolt.	(4)	—	—	—	—	—	—	+	O	—	—
	Boltwood	(5)	—	—	—	—	—	—	—	—	+	O

SITE INDEX 80

20......	Pulpwood	(1)	O[2]	—	—	—	—	—	—	—	—	—
40......	Pulpwood	(1)	O	—	+	O	+	O	—	—	—	—
	Sawtimber	(2)	—	—	+	O	+	O	—	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	+	O	—	—	—	—
60......	Pulpwood	(1)	—	—	+	+	+	+	—	—	—	—
	Sawtimber	(2)	—	—	+	O	+	O	—	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	+	O	—	—	—	—
80......	Pulpwood	(1)	—	—	+	+	+	+	+	+	—	—
	Sawtimber	(2)	—	—	+	O	+	O	+	+	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	+	O	+	+	—	—
	Pulp., saw., & bolt.	(4)	—	—	—	—	—	—	+	O	—	—
	Boltwood	(5)	—	—	—	—	—	—	—	—	+	O
100......	Pulpwood	(1)	—	—	+	+	+	+	+	+	—	—
	Sawtimber	(2)	—	—	+	O	+	O	+	+	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	+	O	+	+	—	—
	Pulp., saw., & bolt.	(4)	—	—	—	—	—	—	+	+	—	—
	Boltwood	(5)	—	—	—	—	—	—	—	—	+	+

[1] Numbers in parentheses correspond to markets in column 2.

[2] + indicates the value standard is attained while O shows it is not being met.

of \$3.00 to \$4.00 for taxes and \$7.00 to \$10.00 for all custodial charges, including taxes. A forest manager desiring to cover his custodial charges and return an average of \$2.00 per acre per year then would expect his forest stand to return say \$27 to \$30 in value increment per decade. This could then become one goal to be tested for his forest and market conditions from data in table 5.

Table 7 shows which stands exceed \$30 and \$100 standards. The \$30 standard was chosen as being an adequate gain for forests being exploited for several uses, with the timber use expected to cover owner costs and yield a modest return. The \$100 standard is used as an example of what might be considered an attractive gain.

It is important to note that the older stands suitable for a variety of markets have a better opportunity of meeting the \$30 and \$100 per acre standards than younger stands. Stands for which there is an improving market are subject to better gains than those in a static market condition.

Those forest stands that do not show promise of meeting the decadal value increment goals should be cut. This forms another single-analysis framework for deciding what to do. The cut may liquidate all the stand, salable portions of it, or enough of it so that money is available for meeting the 10-year goal. If partial cutting is done by featuring properly located clearings, thinnings, and improvement cuttings, the residual timber may make improved value increments in the decade in question as well as in subsequent decades.

Analysis of 10-Year Rates of Return to the Timber Investment

The rate of return is a popular economic yardstick applied to timber as well as to other investments. The rate of return is calculated for a timber stand and compared to a standard to determine if the timber is "financially mature." Rate of return $(1+p)^n$ to the timber investment as used here is calculated as follows:

$$(1+p)^n = \frac{V_n}{V_o}$$

where p = Interest rate earned.
n = Period in years: 10 years in our case.
V_n = Timber value at the end of the period.
V_o = Timber value at the beginning of the period.

Rates of return for our timber situations appear in table 8.

The importance of timber-market development becomes apparent again in table 8. High rates of return result only in a rapidly expanding market due either to the improved product potential of the stand or to markets for new products. When a static market exists at both the beginning and end of the 10-year period, the rates of return to let-it-grow management are unattractive. The only exception to this are those periods when the timber moves in size or specifications into that market. For example, 40-year-old timber on site index 80 valued as sawtimber achieves a prospective 12.2-percent rate of return over the next 10 years. At ages 60, 80, and 100 years, however, the rate drops to 3.1, then 1.5, and 1.2 percent respectively.

The interpretation of this dropping rate of return in a static market needs to be made with care. The decline is fundamental, but the point at which the decline occurs, or its magnitude, depends entirely on minimum product quantities, product values, and tree size and quality distributions. Table 3 shows that the product increment increases quickly, remains stable for a number of years, and declines slowly. During the period of stable production, the value base (table 5) increases rapidly while the value increment holds steady, which accounts for the declining rate of return. Other forest-management practices that alter the skewness of the tree-size and -quality distributions can cause the decline to be delayed or accelerated, depending on the objective of the practice.

Three rate-of-return standards are selected as a basis for judging stand performance. A 2-percent rate was chosen as a suitable criterion for the forest manager interested in a variety of forest uses. The rates of return or rates of utility obtained from other

Table 8. — Rates of return to timber investment in 10-year periods, for selected markets

Age (years)	Present market as basis for valuation		Ten-year rate of return—percent—for selected future markets[1]				
			(1)	(2)	(3)	(4)	(5)
			SITE INDEX 40				
20	Pulpwood	(1)	—	—	—	—	—
40	Pulpwood	(1)	—	—	—	—	—
	Sawtimber	(2)	—	—	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	—
60	Pulpwood	(1)	1.7	—	—	—	—
	Sawtimber	(2)	—	—	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	—
80	Pulpwood[2]	(1)	1.7	6.8	9.6	—	—
	Sawtimber	(2)	—	—	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	—
	Pulp., saw., & bolt.	(4)	—	—	—	—	—
	Boltwood	(5)	—	—	—	—	—
100	Pulpwood	(1)	1.3	6.8	12.7	—	—
	Sawtimber	(2)	—	3.8	5.6	—	—
	Pulpwood & sawtimber	(3)	—	—	2.8	—	—
	Pulp., saw., & bolt.	(4)	—	—	—	—	—
	Boltwood	(5)	—	—	—	—	—
120	Pulpwood	(1)	—	—	—	—	—
	Sawtimber	(2)	—	—	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	—
	Pulp., saw., & bolt.	(4)	—	—	—	—	—
	Boltwood	(5)	—	—	—	—	—

SITE INDEX 60

20......	Pulpwood	(1)	—	—	—	—	—
40......	Pulpwood	(1)	4.1	—	—	—	—
	Sawtimber	(2)	—	—	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	—
60......	Pulpwood	(1)	1.3	8.7	10.7	—	—
	Sawtimber	(2)	—	8.1	10.1	—	—
	Pulpwood & sawtimber	(3)	—	—	5.5	—	—
80......	Pulpwood	(1)	0.9	12.8	13.8	—	—
	Sawtimber	(2)	—	2.8	3.7	—	—
	Pulpwood & sawtimber	(3)	—	—	2.4	—	—
	Pulp., saw., & bolt.	(4)	—	—	—	—	—
	Boltwood	(5)	—	—	—	—	—
100......	Pulpwood	(1)	neg.	14.5	15.0	—	—
	Sawtimber	(2)	—	1.8	2.3	—	—
	Pulpwood & sawtimber	(3)	—	—	1.6	—	—
	Pulp., saw., & bolt.	(4)	—	—	—	—	—
	Boltwood	(5)	—	—	—	—	—
120......	Pulpwood	(1)	neg.	18.2	18.6	21.3	—
	Sawtimber	(2)	—	1.3	1.7	4.0	—
	Pulpwood & sawtimber	(3)	—	—	1.2	3.6	—
	Pulp., saw., & bolt.	(4)	—	—	—	2.2	—
	Boltwood	(5)	—	—	—	—	3.7

SITE INDEX 80

20......	Pulpwood	(1)	10.0	—	—	—	—
40......	Pulpwood	(1)	3.3	9.8	11.7	—	—
	Sawtimber	(2)	—	12.2	14.1	—	—
	Pulpwood & sawtimber	(3)	—	—	7.9	—	—

CONTINUED

Table 8. — Continued

Age (years)	Present market as basis for valuation		Ten-year rate of return—percent—for selected future markets[1]				
			(1)	(2)	(3)	(4)	(5)
60	Pulpwood	(1)	neg.	14.4	15.0	—	—
	Sawtimber	(2)	—	3.1	3.6	—	—
	Pulpwood & sawtimber	(3)	—	—	2.7	—	—
80	Pulpwood[2]	(1)	neg.	18.8	19.0	21.2	—
	Sawtimber	(2)	—	1.5	1.8	3.6	—
	Pulpwood & sawtimber	(3)	—	—	1.4	3.3	—
	Pulp., saw., & bolt.	(4)	—	—	—	1.8	—
	Boltwood	(5)	—	—	—	—	15.9
100	Pulpwood	(1)	neg.	23.3	23.3	27.9	—
	Sawtimber	(2)	—	1.2	1.4	5.0	—
	Pulpwood & sawtimber	(3)	—	—	1.2	4.9	—
	Pulp., saw., & bolt.	(4)	—	—	—	1.9	—
	Boltwood	(5)	—	—	—	—	2.1
120	Pulpwood	(1)	—	—	—	—	—
	Sawtimber	(2)	—	—	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	—
	Pulp., saw., & bolt.	(4)	—	—	—	—	—
	Boltwood	(5)	—	—	—	—	—

[1] Numbers in parentheses correspond to markets in column 2.

[2] An 80-year-old stand on site 40 land is now merchantable only for pulpwood. In 10 years it is suitable for 3 markets. Its rate of return depends upon these future markets. It will earn 1.7 percent in a pulpwood market, 6.8 percent in a sawtimber market, and 9.6 percent in the combination market.

uses should be enough to add to this modest timber return to make woodland ownership attractive. Four percent was chosen as a lower limit for investment alternatives, and 6 percent was selected to reflect a criterion for those who might seek alternative investments. Table 9 contrasts stand performance against these criteria.

A comparison of value-increase performance in table 7 with the rate-of-return performance in table 9 points up important differences between these two yardsticks. Important value increases are made by older stands while high rates of return are made by younger stands. Those stands that do not meet the appropriate decadal rate of return should be cut according to this yardstick. Again, as with the value-increase yardstick, partial cuttings are feasible. Trees that do not meet the rate-of-return criterion should be selected for cutting. Guides for financial maturity *(Trimble and Mendel 1968)* can be used to select these trees.

Table 9. — Estimated stand performance at 2-, 4-, and 6-percent rates of return criteria

Age (years)	Present market[1] as basis for valuation		Selected future markets[1]														
			(1)			(2)			(3)			(4)			(5)		
			2	4	6[2]	2	4	6[2]	2	4	6[2]	2	4	6[2]	2	4	6[2]
	SITE INDEX 40																
20	Pulpwood	(1)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
40	Pulpwood	(1)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Sawtimber	(2)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
60	Pulpwood	(1)	O	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Sawtimber	(2)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
80	Pulpwood	(1)	O	—	—	+	+	+	+	+	+	—	—	—	—	—	—
	Sawtimber	(2)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Pulp., saw., & bolt.	(4)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Boltwood	(5)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
100	Pulpwood	(1)	O	—	—	+	+	+	+	+	+	—	—	—	—	—	—
	Sawtimber	(2)	—	—	—	+	O	—	+	+	O	—	—	—	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	—	—	+	O	—	—	—	—	—	—	—
	Pulp., saw., & bolt.	(4)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Boltwood	(5)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

SITE INDEX 60

20.	Pulpwood	(1)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
40.	Pulpwood	(1)	+	+	O	—	—	—	—	—	—	—	—	—	—	—	—
	Sawtimber	(2)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
60.	Pulpwood	(1)	O	—	—	+	+	+	+	+	+	—	—	—	—	—	—
	Sawtimber	(2)	—	—	—	+	+	+	+	+	+	—	—	—	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	—	—	+	+	O	—	—	—	—	—	—
80.	Pulpwood	(1)	O	—	—	+	+	+	+	+	+	—	—	—	—	—	—
	Sawtimber	(2)	—	—	—	+	O	—	+	O	—	—	—	—	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	—	—	+	O	—	—	—	—	—	—	—
	Pulp., saw., & bolt.	(4)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Boltwood	(5)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
100.	Pulpwood	(1)	O	—	—	+	+	+	+	+	+	—	—	—	—	—	—
	Sawtimber	(2)	—	—	—	O	—	—	+	O	—	—	—	—	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	—	—	O	—	—	—	—	—	—	—	—
	Pulp., saw., & bolt.	(4)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Boltwood	(5)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
120.	Pulpwood	(1)	O	—	—	+	+	+	+	+	+	+	+	+	—	—	—
	Sawtimber	(2)	—	—	—	O	—	—	O	—	—	+	+	O	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	—	—	O	—	—	+	O	—	—	—	—
	Pulp., saw., & bolt.	(4)	—	—	—	—	—	—	—	—	—	+	O	—	—	—	—
	Boltwood	(5)	—	—	—	—	—	—	—	—	—	—	—	—	+	O	—

CONTINUED

Table 9. — Continued

Age (years)	Present market[1] as basis for valuation		Selected future markets[1]														
			(1)			(2)			(3)			(4)			(5)		
			2	4	6[2]	2	4	6[2]	2	4	6[2]	2	4	6[2]	2	4	6[2]
	SITE INDEX 80																
20	Pulpwood	(1)	+	+	+	—	—	—	—	—	—	—	—	—	—	—	—
40	Pulpwood	(1)	+	O	—	+	+	+	+	+	+	—	—	—	—	—	—
	Sawtimber	(2)	—	—	—	+	+	+	+	+	+	—	—	—	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	—	—	+	+	+	—	—	—	—	—	—
60	Pulpwood	(1)	O	—	—	+	+	+	+	+	+	—	—	—	—	—	—
	Sawtimber	(2)	—	—	—	+	O	—	+	O	—	—	—	—	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	—	—	+	O	—	—	—	—	—	—	—
80	Pulpwood	(1)	O	—	—	+	+	+	+	+	+	+	+	+	—	—	—
	Sawtimber	(2)	—	—	—	O	—	—	O	—	—	+	O	—	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	—	—	—	—	—	+	O	—	—	—	—
	Pulp., saw., & bolt.	(4)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Boltwood	(5)	—	—	—	—	—	—	—	—	—	—	—	—	+	+	+
100	Pulpwood	(1)	O	—	—	+	+	+	+	+	+	+	+	+	—	—	—
	Sawtimber	(2)	—	—	—	O	—	—	O	—	—	+	+	O	—	—	—
	Pulpwood & sawtimber	(3)	—	—	—	—	—	—	O	—	—	+	+	O	—	—	—
	Pulp., saw., & bolt.	(4)	—	—	—	—	—	—	—	—	—	O	—	—	—	—	—
	Boltwood	(5)	—	—	—	—	—	—	—	—	—	—	—	—	+	O	—

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[1] Numbers in parentheses correspond to markets in column 2.

[2] Column numbers 2, 4, 6 indicate rate-of-return standards. O indicates stand performance did not meet the standard while + indicates that the standard was equalled or exceeded.

The Effects of Custodial Charges and Land Values

The effects of custodial charges on value increments was discussed briefly in an earlier section. The effects of these charges and land values on the rate of return from letting timber grow can be understood more clearly by expanding the rate-of-return equation.

Let: ΔV = Timber value increase obtained by letting timber grow.

V_l = Initial value of land, not including timber.

V_t = Initial value of timber growing stock.

C = Required decadal value increase needed to cover annual custodial charges.

Then:

$$V_n = V_t + V_l + \Delta V - C$$

$$V_o \text{ becomes } V_t + V_l$$

and:

$$(1+p)^n = \frac{V_t + V_l + \Delta V - C}{V_t + V_l}$$

The effects of these charges and the addition of land value become apparent by considering the changes in $(1+p)^n$ wrought by different amounts of C and V_l.

1. If C exceeds ΔV, the rate of return disappears. Any value for C will reduce the rate of return to letting timber grow.

2. Introducing V_l into the denominator as well as the numerator will reduce the rate of return but will not eliminate it. Its effect varies depending on the size of V_t and V_l.

The illustration provided by table 10 shows the effects of constant decadal charges of \$20 and land value of \$50 on the rates earned by a range of timber values common to our example.

For a constant value increment, a constant custodial charge will adversely affect the rate of return to high-value timber to a greater extent than low-value timber. The difference is entirely due to the value base. Our example in table 10 shows that 66 percent of the original rate was retained for a \$50 timber investment while only 58 percent was retained for a \$400 timber investment. For a constant land value, on the other hand, rates of return to timber alone will be reduced more for low-value stands

Table 10. — Effect of custodial charges and land values on the rate of return to investments in timber

Timber value			Decadal custodial charge			Land values			Combined charges and values			
Beginning value, dollars	10-year increase, dollars	Rate of return, int. rate	Amount (dollars)	Rate of return		Amount (dollars)	Rate of return		Amount		Rate of return	
				Interest rate	Percent of timber rate		Interest rate	Percent of timber rate	Charge, dollars	Value, dollars	Interest rate	Percent of timber rate
(V_t)	(ΔV_t)	(1)	(C)	(2)	(5)	(V_1)	(3)	(5)			(4)	(5)
50	50	7.2	20	4.8	66	50	4.2	58	20	50	2.7	37
100	50	4.2	20	2.7	64	50	2.9	69	20	50	1.8	43
200	50	2.3	20	1.4	61	50	1.8	78	20	50	1.1	47
400	50	1.2	20	.7	58	50	1.1	92	20	50	.6	50

[1] $(1+op)^{10} = \dfrac{V_t + \Delta V_t}{V_t}$ Rate of return to timber investment only.

[2] $(1+op)^{10} = \dfrac{V_t + \Delta V_t - C}{V_t}$ Rate of return to timber affected by annual custodial charges.

[3] $(1+op)^{10} = \dfrac{V_t + V_1 + \Delta V_t}{V_t + V_1}$ Rate of return to timber affected by introducing land values.

[4] $(1+op)^{10} = \dfrac{V_t + V_1 + \Delta V_t - C}{V_t + V_1}$ Rate of return to timber affected by both custodial charges and land values.

[5] $(1+p)^{10}$ Compares rate of return in preceding column as a percent of the rate of return to timber alone in column 3.

than for high-value stands. In table 10 the $400 timber investment retained 92 percent of its rate of return to timber alone while the $50 stand retained only 58 percent. The effects of the combined charges and values as treated here are the product of the two individual effects. They produce a general reduction in the rate of return to timber alone.

[illegible] "Let-it-Grow" Alternative

Decisions are rarely made on the basis of a single factor. Usually a course of action is decided on after considering it from several points of view. Each single factor presented here represents a different economic point of view. A formal presentation of the outcomes of the let-it-grow alternative for all factors should sharpen the forest manager's judgment so he can make a better decision. This is done by example in table 11. A forest manager can follow this example to develop a similar array for his own situation. If his forest and markets conform to the situations described here, he can develop his evaluation from data in this publication. More than likely, though, he will have to trace out the stand-table projection methods and market synthesis described to develop his own basic data for evaluation.

These quantitative data can be generalized for the forest and market situation described in table 11 to provide management-decision information as follows:

1. The owner has the option to cut it all as well as let it grow according to the per-acre volume standards outlined in this paper. Also, he has enough volume of each individual product so that partial liquidation options are clearly open to him.
2. The per-acre sawtimber and boltwood growth standards will be met and exceeded while the pulpwood components of the stand exhibit negative production and do not meet the standard.

Table 11. — Evaluation array (10-year basis) for judging if the let-it-grow management option is worthwhile

1. Condition for evaluation:
   Age of timber stand — 80 years
   Site index of timberland — 80 feet
   Existing market — Pulpwood & sawtimber (3)
   Prospective markets — Pulpwood & sawtimber (3)
   — Pulpwood, sawtimber & boltwood (4)
   — Boltwood (5)

2. Basis for evaluation:

Item	Product	Measure	Estimated performance	Performance compared to acceptable standards[1]						
				Merchantability standards	Growth standards	Value increase standards		Rate of return on timber standards		
						$30	$100	2%	4%	6%
Present volumes	— Pulpwood	— cords	30.3	+	—	—	—	—	—	—
(Table 3)[2]	— Sawtimber	— ft. b. m.	16,075	+	—	—	—	—	—	—
(Table 4)	— Boltwood	— ft. b. m.	950	+	—	—	—	—	—	—
Volume increase	— Pulpwood	— cords	1.6	—	O	—	—	—	—	—
(Table 3)	— Sawtimber	— ft. b.m.	1,415	—	+	—	—	—	—	—
(Table 4)	— Boltwood	— ft. b. m.	880	—	+	—	—	—	—	—
Present value (Table 5)		— dollars	301	—	—	—	—	—	—	—

Value increase (Table 5)	— Pulpwood & sawtimber market (3) — dollars	47	—	—	+	O	—	—	—
(Table 7)	— Pulpwood, sawtimber & bolt market (4) — dollars	116	—	—	+	+	—	—	—
	— Boltwood market (5) — dollars	88	—	—	+	O	—	—	—
Rate of return on timber (Table 8) (Table 9)	— Pulpwood & sawtimber market (3) — percent	1.4	—	—	—	—	O	O	O
	— Pulpwood, sawtimber & bolt market (4) — percent	3.3	—	—	—	—	+	O	O
	— Boltwood market (5) — percent	2.6	—	—	—	—	+	O	O

---

[1] Performance meeting standards is indicated by +, not meeting standards by O.

[2] Tables 3, 5, and 8 are sources for estimated performance; tables 4, 7, and 9 are sources for the comparison with performance standards.

3. Per-acre value increases meet custodial charges for all potential market conditions. A boltwood market must be present for the stand to make attractive per-acre value increases.
4. Rates of return on the timber investment are low. In fact, a boltwood market must be present to make a 2-percent (multiple-use rate) rate of return on timber alone.

This type of evaluation provides the forest owner valuable economic background information to use in conjunction with his other responsibilities, commitments, and circumstances to help decide whether to cut it or let it grow. The first generalization suggests that he has other options open to him. Added considerations beyond the scope here need to be made to develop the similar information required for him to estimate whether partial liquidation or additional investments in forest-management practices would be advantageous to him.

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EROSION CONTROL on Logging Roads in the Appalachians

by James N. Kochenderfer

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RICHARD D. LANE, DIRECTOR

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EROSION CONTROL on Logging Roads in the Appalachians

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WHY WORRY ABOUT A LITTLE MUD?

IN THE STEEP TERRAIN of the Appalachian Mountains much damage to forest streams is caused by erosion on logging roads. Muddy water that is unsuitable for fish, swimming, or human consumption often can be traced to these eroding roads. This paper has been prepared to sum up what land managers know about preventing and controlling erosion on logging roads in the Appalachians.

In most respects, erosion on forest roads is like erosion on farmland. The basic problem in both places is the swift flow of storm water over bare, steep ground from which the protective plant cover has been removed. The effects of some farming practices, such as cutting hay, are similar to the effects of cutting trees. Neither practice creates erosion problems because it does not expose bare soil. Also, on both kinds of land the careful manager protects the soil with a plant cover whenever possible. When harvest of the field or forest crop removes this protective plant cover, the wise land manager makes every effort to minimize damage to the exposed soil.

In the woods, roads are practically the only place where soil is dangerously exposed. The following pages tell how forest land managers can successfully cope with some of the commonest erosion problems on logging roads in the Appalachians.

For centuries we have known that erosion is rarely a problem on undisturbed forested soils. Forests are shields that protect the soil from erosion by soaking up rain faster than it falls. Leaves and twigs from the trees supply an annual addition to the soil of forest litter, which absorbs the impact of falling rain. Live roots bind forest soil together and, combined with this decaying litter, provide passageways for water into the soil. Thus surface runoff, the major cause of erosion, rarely occurs on undisturbed, litter-covered forest soils.

Although for many years some people have associated timber harvesting with deterioration of forest land and streams, experience over the last quarter-century has convinced most land managers that the mere cutting of trees is not the cause of erosion damage (fig. 1). Now we know that the real sources of this damage are the roads used to remove harvested products from the forest.

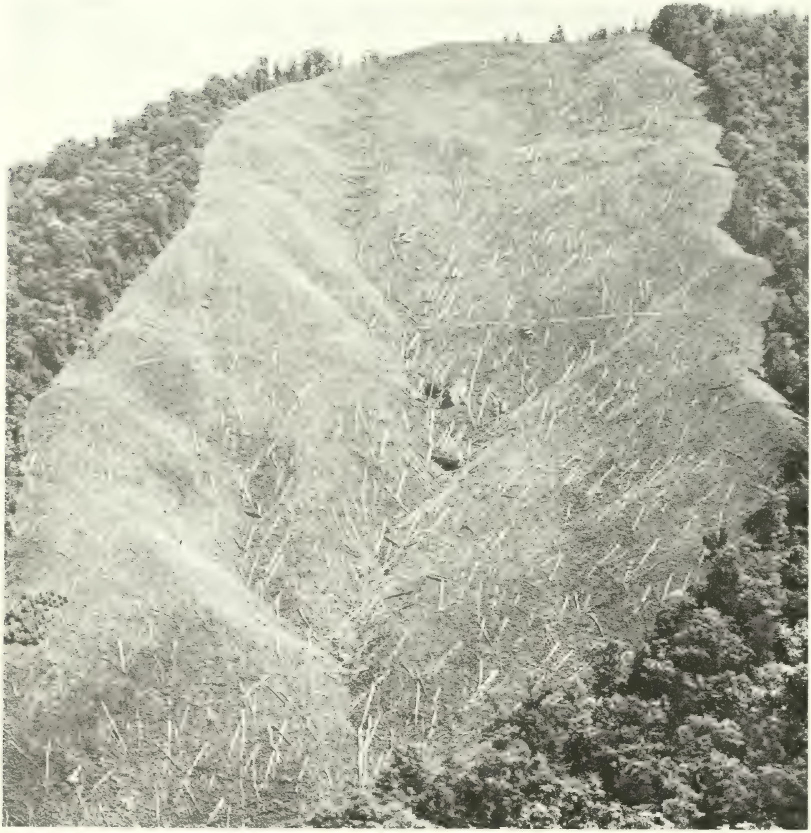


Figure 1.—Cutting all trees and leaving them where they fell on this watershed at Coweeta Hydrologic Laboratory near Franklin, N. C. did not increase erosion, nor did annually mowing the brush for 15 years afterward. The only roads constructed on this watershed were well-located contour roads barely visible in the upper part of the picture.

Although much of the original forest canopy is destroyed by cutting the trees, the litter cover is only slightly disturbed and amply protects the soil until a new canopy grows to furnish more litter.

Roads, however, present more permanent problems that often are not solved by natural vegetation, for their construction removes the all-important forest litter, which then cannot build up as long as the road is in use (fig. 2). The resulting soil compaction and loss of protective and absorbent litter prevent rain from soaking into the soil surface as rapidly as it falls. This causes water to collect on the road surface and run over exposed soils.

The runoff water moves fastest on steep roads, rapidly building up its erosive power, tearing soil loose and carrying it along, producing rutted, muddy roads over which forest products cannot efficiently be moved.

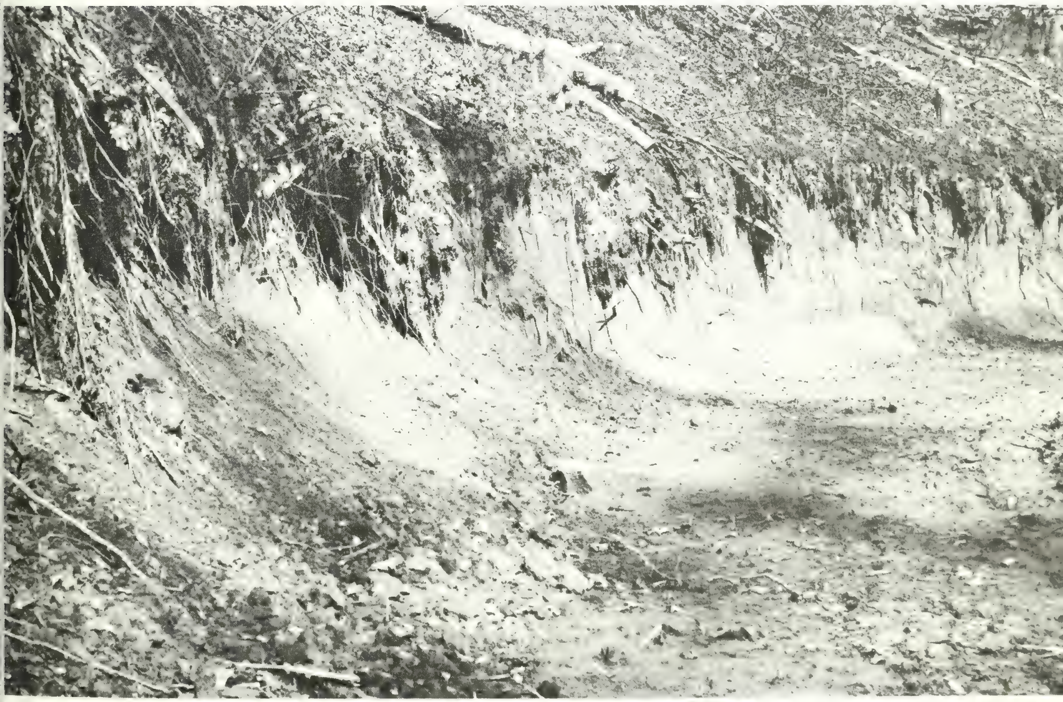


Figure 2.—Roadbuilding removes the litter that protects soil against erosion.

The erosion of roads also can contribute tremendous amounts of mud to formerly clear forest streams, destroying much of their value for men and wildlife.

Even small amounts of mud in water greatly decrease its usefulness. Visibly muddy stream water is not suitable for human consumption, and small amounts of mud are very harmful to fish that normally inhabit clear mountain streams. The economic damage is widespread, for most industries cannot use muddy water, and when sediment carried by muddy streams is deposited behind dams, their storage capacity is reduced.

PLANNING THE ROAD SYSTEM

Access always is necessary before forest resources can be used or managed, and this requires roads. Logging roads, once constructed, become a permanent part of the forest landscape. Although many logging roads are considered temporary when built, there is a good chance that they will be used to provide future access, even though they may be too steep and poorly located to provide efficient access or to protect against serious erosion damage.

Thus it is important to plan road systems that can provide permanent and efficient access to large areas without damaging other resources, such as streams, which may supply drinking water or fishing. In the past, however, most forest roads were planned to serve single logging operations with little regard to future access or damage to water supplies. Logging roads were commonly so steep that they could not be protected against erosion, or they were located next to streams, which they often polluted with sediment.

Careful planning can eliminate these undesirable practices that result in washed-out roads and silted streams (fig. 3). Planning can be made easier by using aerial photographs and topographic maps. These are valuable tools for planning logging road systems because they permit large areas to be viewed at once. This greatly facilitates the design of road systems and enables them to serve

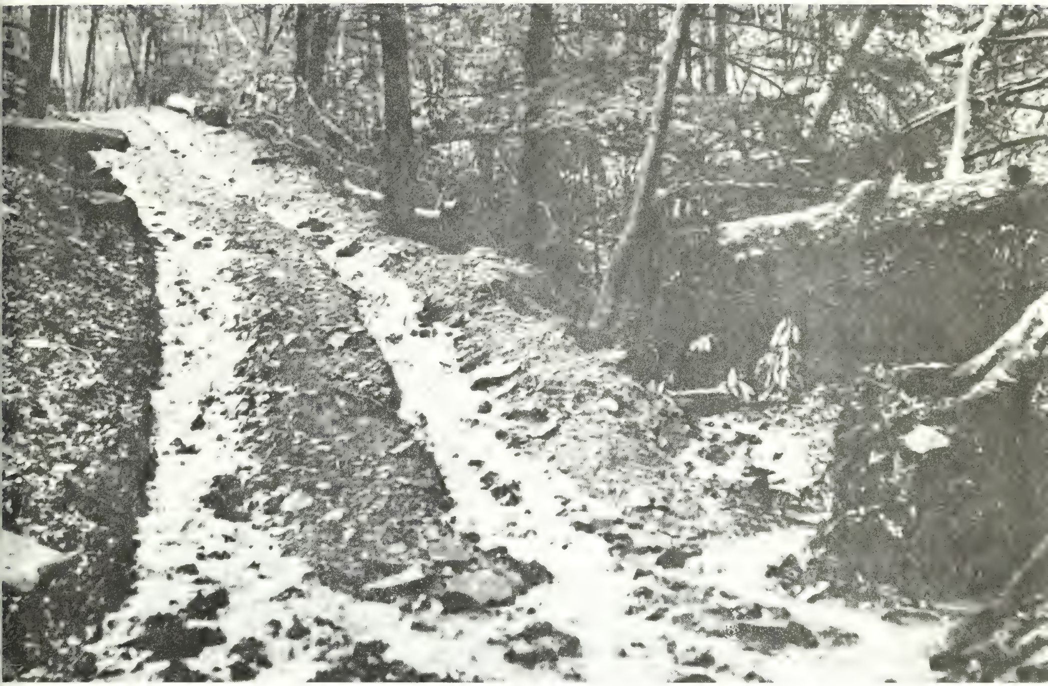


Figure 3.—Excessive erosion and costly damage caused by poor logging-road location and lack of adequate drainage.

the largest possible areas. It also often reduces the need for steep logging roads by showing routes that avoid such obstacles as rock outcrops, property lines, and wet areas.

Careful planning can minimize the amount of land in roads. This makes for more efficient logging and is also one of the best ways to reduce erosion on logged areas. Studies on the Fernow Experimental Forest have shown that good planning can reduce skidroad area by as much as 40 percent.

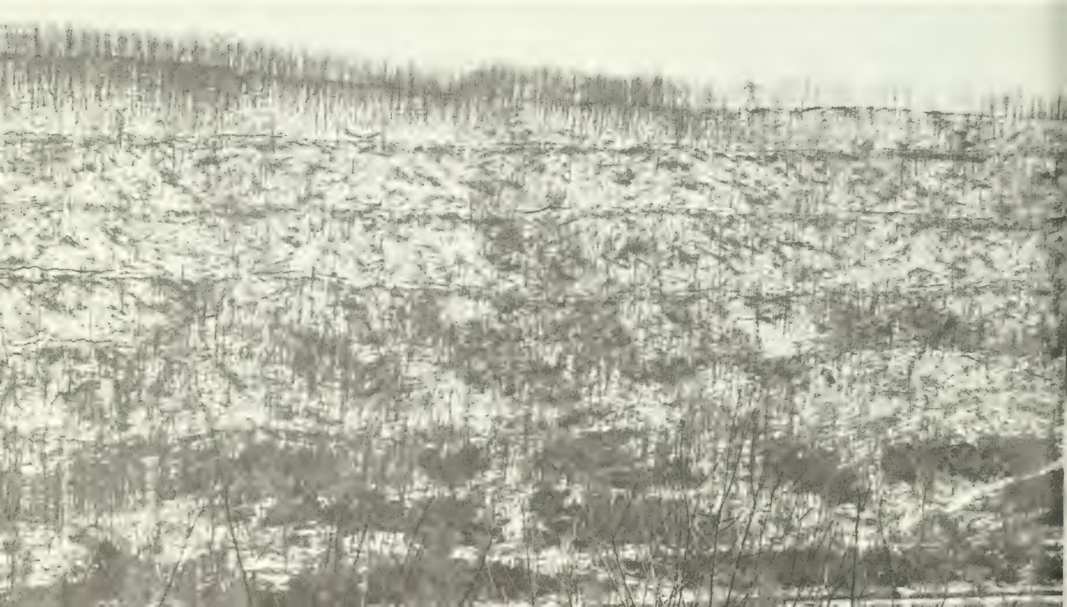
Erosion can be further reduced, and efficiency increased, by planning skidroad and truck road systems together, for skidroad grade and location, and skidding direction, usually depend on the location of logging truck roads.

Roads in steep terrain should be planned so tree-length logs can be winched uphill to them. This reduces disturbances because the ends of logs pulled uphill do not readily gouge the forest floor.

Although the best rule is to locate roads and landings as far from streams as possible, when this is not practical, logs should be winched away from streams, rather than skidded across or down streambeds. This helps to keep water clean and reduces damage to stream channels. Also, it is easier for choker setters to pull winch lines downhill, and control is better on logs pulled uphill. Once logs have been winched uphill to roads, they can either be loaded on trucks or skidded down the road to landings.

Hauling direction is another important factor in planning logging-road systems. Roads should be designed to permit downhill hauling on gentle grades because it is more economical than uphill hauling and results in less wear on equipment and road surfaces. A system consisting of one climbing road and several spur roads that closely follow the contour of the land works well in many areas of the rugged Appalachians. The climbing road takes trucks and machinery to all elevations, but logging actually is done from the spur roads that branch off from the climbing road and run on gentle grades into the timber (fig. 4).

Figure 4.—A well-planned logging-road system on topography similar to and within a few miles of the system shown in figure 5. Note that the roads closely follow the contour and provide efficient access to the entire area. One section of the climbing road is shown in the lower right.



The best logging roads should be planned for areas of greatest use. Sections of road near the ends of road systems and in other areas of light use do not have to be as well constructed as main roads that receive heavy use.

On small ownerships, one well-located road with a well-planned skidroad system often provides adequate access to the whole tract. However, property boundaries often prevent fitting logging road systems to topography, and roads cannot be located properly. Under these conditions the erosion-control measures that will be discussed are even more necessary.

Another reason for careful planning is that poorly arranged roads (fig. 5) present an ugly view to other forest users. An orderly road arrangement (fig. 4) presents a more pleasing view. Many problems in public relations might be avoided if more care were used on logging road systems—before, during, and after timber harvest.

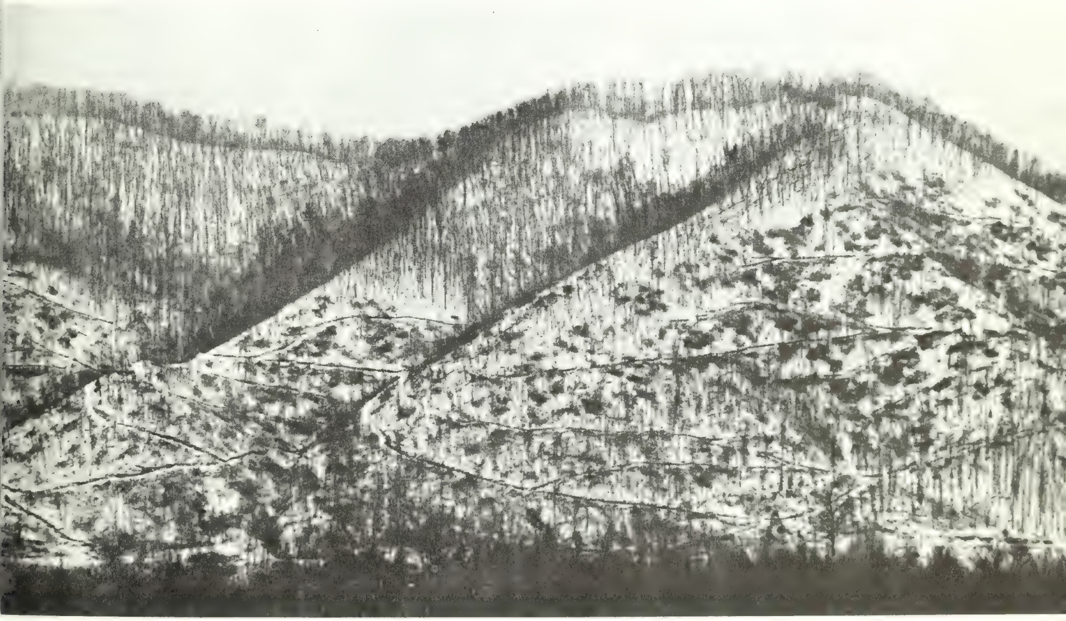


Figure 5.—A poorly planned logging-road system. Note the steep roads and haphazard arrangement, resulting in many dead-end roads.

LOGGING-ROAD LOCATION

Roads tentatively located on topographic maps or aerial photographs must be laid out on the land before their final location can be established. It is a good idea to take aerial photographs into the field when locating logging roads so that proposed routes can be followed readily and alternate routes can be chosen if the need arises. Locating roads is easier when two-man teams are used.

In hardwood regions it is easiest to lay out logging roads when trees are leafless. Plastic flagging can be used to mark proposed locations for logging roads. Avoid hanging flagging on objects like rotten branches that may break off in the interval between road layout and construction. Plastic flagging of different colors may be used to distinguish truck roads from skidroads. Road locations may be changed several times before a satisfactory route is found.

To avoid confusion, remove all flagging except that marking final road location before construction begins.

Grade

One of the most important things that determines logging-road location is the grade or steepness of the road. Road grade is commonly expressed in percent. A road with a 10-percent grade, for example, rises or drops 10 feet for every 100 feet of horizontal distance. Road grade can be measured with several instruments; one of the most common and most readily available is the Abney hand level (fig. 6).

Experience has shown that steep roads do not provide efficient access to the stand and that it is difficult to control erosion on them (fig. 7). Slipping and sliding is a greater problem on steep grades. Even a single short section of steep or muddy logging road can restrict the use of several miles of road beyond it. Gentle grades permit timber to be harvested economically without damaging other natural resources. Average downhill skidding speed usually is faster on grades ranging from 5 to 15 percent than on either level or steeper grades.

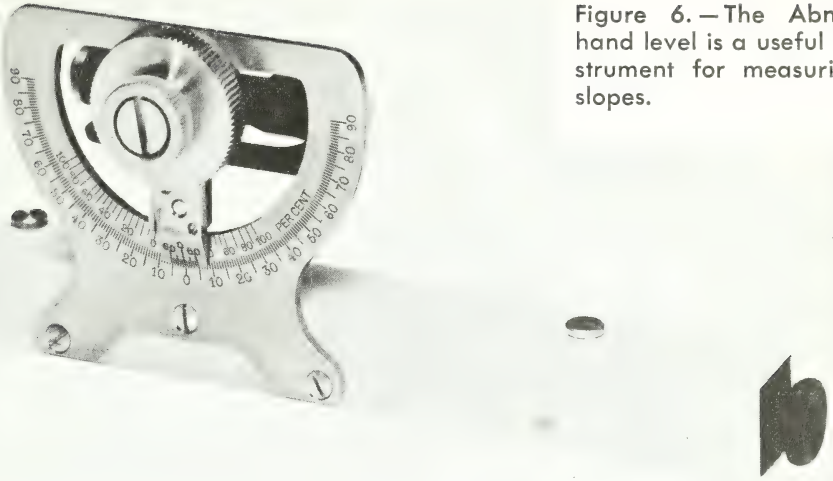


Figure 6. — The Abney hand level is a useful instrument for measuring slopes.

Figure 7. — Well-located and well-constructed roads with gentle grades are required for the efficient operation of modern logging equipment in the rugged Appalachian Mountains. Because these wide roads expose more soil than the narrower roads formerly used, careful erosion control is important.

Roads located on gentle grades provide efficient access for many other uses and can readily be converted into higher class road systems. But long uninterrupted grades should be broken with occasional grade breaks to facilitate drainage. Sometimes sharp curves and switchbacks are unavoidable on steep land; and when they are used, road grades should be reduced to facilitate truck travel. Short sections of logging roads may require higher grades to get around obstacles that cannot be removed economically or avoided by careful planning. If at all possible, steep grades should be restricted to lightly used roads; but, when steep sections are unavoidable, extra measures, such as gravel and additional culverts, are needed to protect the road against erosion.

A minimum grade of 3 percent is desirable to provide adequate drainage on logging roads. When the grade is less than this, water collects in every small depression on the road surface and will not run into drainage structures. Locating contour roads with frequent grade breaks of ± 5 percent to take advantage of terrain and natural drains helps provide proper drainage. Flat areas such as bottomland and broad ridge tops may seem to be attractive road sites because of low initial construction costs, but they usually are poor locations because they often become trough-like and hard to drain. Hillsides usually afford the best locations for logging roads because they permit drainage, less water is encountered on them, and they often provide stronger material for roadbeds (fig. 8). Steepest hillsides should be avoided because here construction costs usually are highest and danger from slips is greatest.

Foresters generally agree that grades on logging roads should seldom exceed 10 percent. Roads laid out on a 10-percent grade often end up being steeper. Experience on the Fernow Experimental Forest has shown that roads laid out on a 10-percent grade will vary between 5 and 15 percent after construction. Constructed roads also vary from proposed locations because they are often built around obstacles like large trees and rocks that could not be avoided during layout. However, changes from carefully selected locations should be done cautiously. Too often roads are built away from original locations simply because initial construc-

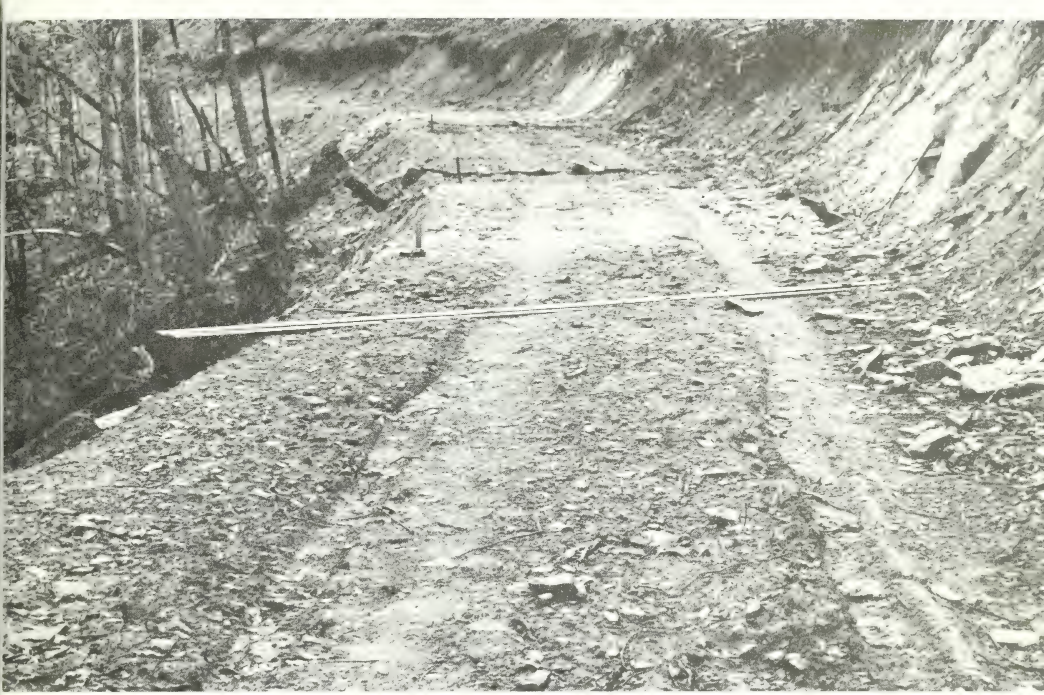


Figure 8.—A properly located and properly constructed logging truck road. The road is on a hillside and is well above a stream. The long climbing grade is broken by culverts, and the roadbed contains a high proportion of natural stone.

tion costs appear cheaper, and little thought is given to future uses or possible damage to other resources.

Filter Strips

Experience has shown that a protective strip of absorbent, undisturbed forest soil between logging roads and streams usually prevents muddy road water from reaching streams. This strip of undisturbed land, often called a filter strip, should be wide enough to absorb all the muddy water that runs off road surfaces (fig. 9). Sediment in muddy water is collected on the undisturbed litter and soil, and only clear water enters the streams.

The required filter-strip width varies with the steepness of slope between road and stream, but the effectiveness of filter strips is

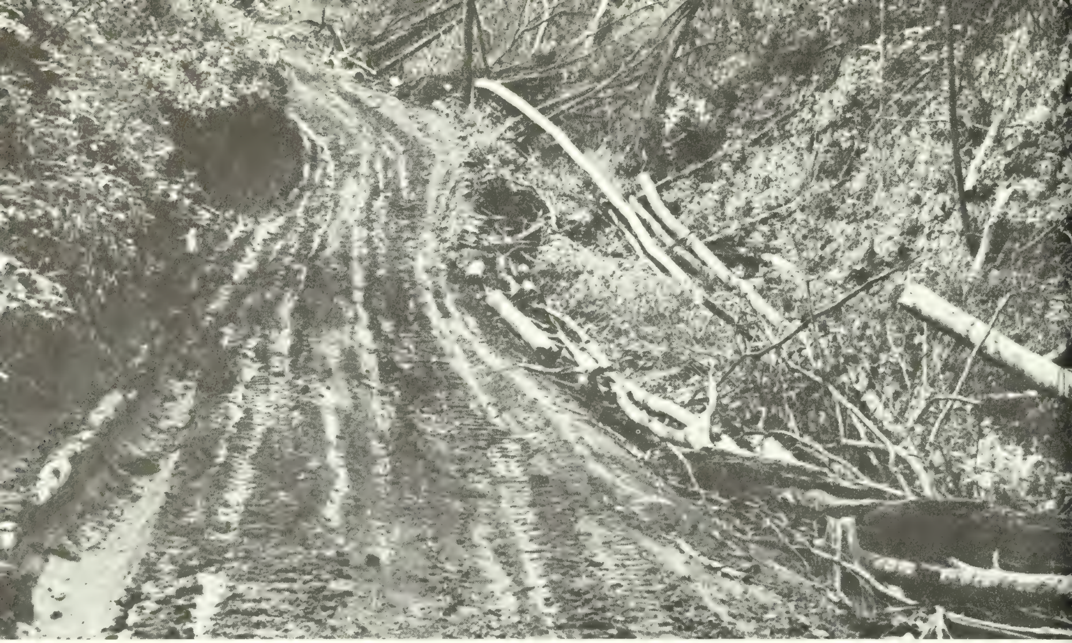


Figure 9.—Serious stream pollution occurred when this logging road was located too close to a stream. The filter strip between the road and stream was not wide enough to prevent mud washed off the road from reaching the stream.

increased by obstructions such as logs, slash, depressions, and rocks, which trap sediment. A minimum distance of 100 feet is recommended between logging roads or landings and streams.

Often, steep hillsides will require that logging roads be built even further than 100 feet from streams to keep mud out of them. Sometimes obstructions such as property lines and rock outcrops will force logging roads to be built closer to streams. In these cases, piling slash cleared from road rights-of-way on the slope below overcast soil, and seeding overcast soil to grass, will help minimize stream damage.

Suitable stream-crossing sites are a prime consideration when locating logging roads. Neither deeply cut stream channels nor those in soft, muddy soil can be crossed easily. A narrow place with relatively low banks and firm, rocky soil usually makes the best crossing. Road alinement on approaches to crossing sites must be straight enough so that loaded trucks can cross easily.

DRAINAGE

The usefulness and permanence of logging roads depends to a large extent on how well they are drained. Logging roads must be adequately drained to protect road surfaces from erosion and to prevent mud from spreading over nearby land and into streams. There are many sad examples throughout the Appalachians where uncontrolled water has eroded the surfaces of logging roads, thus destroying their usefulness and necessitating costly repairs (fig. 10). Water also softens and dissolves road material, weakening roadbeds until they will not support equipment. It is especially important to drain forest roads during logging operations, a time when erosion is greatly accelerated because the roads are being continuously disturbed.

Culverts

Several drainage devices have been developed for controlling water flow on logging roads. Culverts are probably most common.

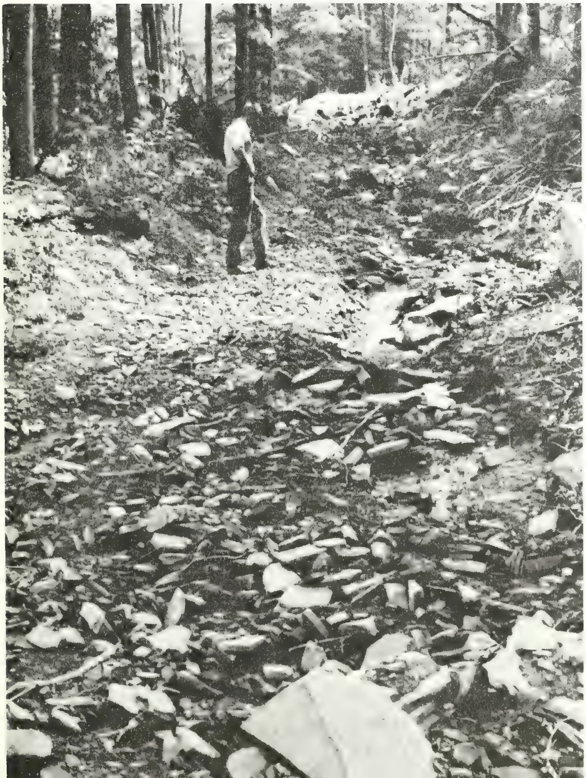


Figure 10.—This logging road is only 2 years old, but uncontrolled water has destroyed its usefulness. Costly road repairs will be required before it can again provide efficient access. Installation of simple drainage structures would have prevented this erosion and would have preserved the road for future use.

Those used on logging roads are usually constructed from metal, lumber, or logs. The minimum effective culvert length for most logging roads is 14 feet; culverts placed in fills must be longer so that they do not become plugged with fill material.

The tabulation below shows culvert diameter required for drainage areas in the southern Appalachian forests. The type I column applies to normal forest soils below 3,000 feet. The type II column is for drainage above 3,000 feet and for shallow soils with frequent rock outcrops at any elevation:

	Area above pipe[1]	
Pipe diameter (inches)	*Type I (acres)*	*Type II (acres)*
12	9	2
15	16	4
18	25	7
21	40	12
24	55	16
30	84	27
36	130	47
42	190	64
48	260	90
54	335	120
60	400	160
66	550	205
72	650	250
78	920	350

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[1] Unpublished data, courtesy James E. Douglass, Coweeta Hydrologic Laboratory.

Metal culverts are superior for most drainage needs, except interception of surface runoff. Their initial cost is high, but they last much longer and require less maintenance than wooden culverts or bridges. Serious consideration should be given to using metal culverts on main haul roads, especially in deep fills where periodic replacement of wooden drainage structures is difficult and costly. Installing metal culverts in deep fills is nearly always more satisfactory, and often cheaper, than building wooden bridges.

Culverts used on lower-cost logging truck roads are usually constructed from lumber, logs, or a combination of the two, and are either open-top or closed-top (fig. 11). These two types of wooden culverts, when properly installed and maintained, will adequately drain road-surface runoff, springs, seeps, and other small sources of water.

Open-top culverts (figs. 12 and 13) are most useful for intercepting runoff flowing down road surfaces. However, log-skidding tends to damage and plug up open-top culverts, rendering them

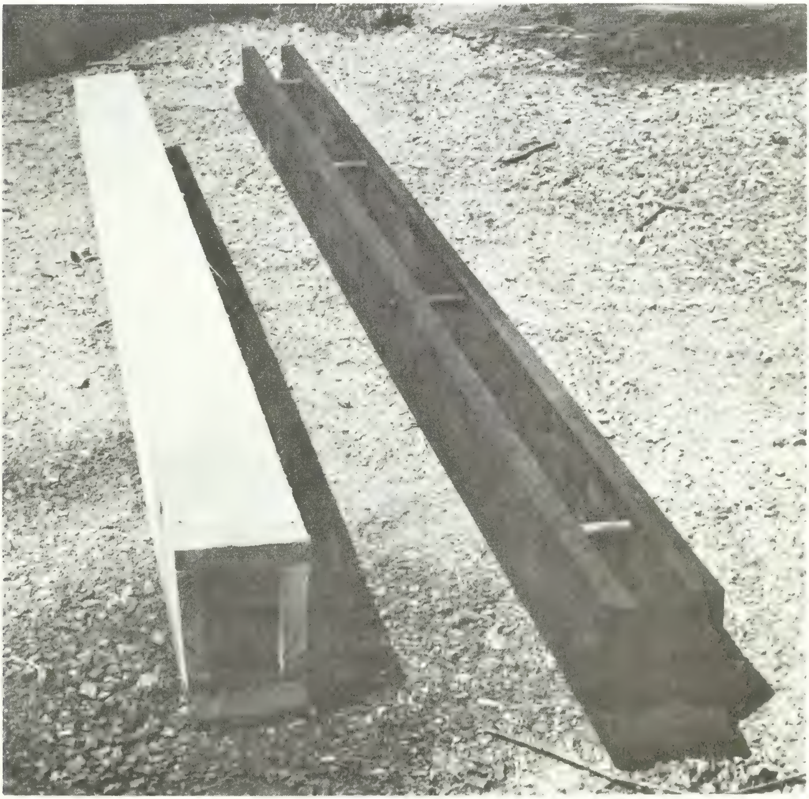


Figure 11.—Closed-top culvert (left) and open-top culvert (right). Both of these culverts were constructed from low-grade 2 x 8 strong hardwood lumber. Larger boards can be used to increase culvert capacity. Culverts should be strongly constructed from hardwood lumber and carefully installed to withstand the pressures exerted by loaded logging trucks.

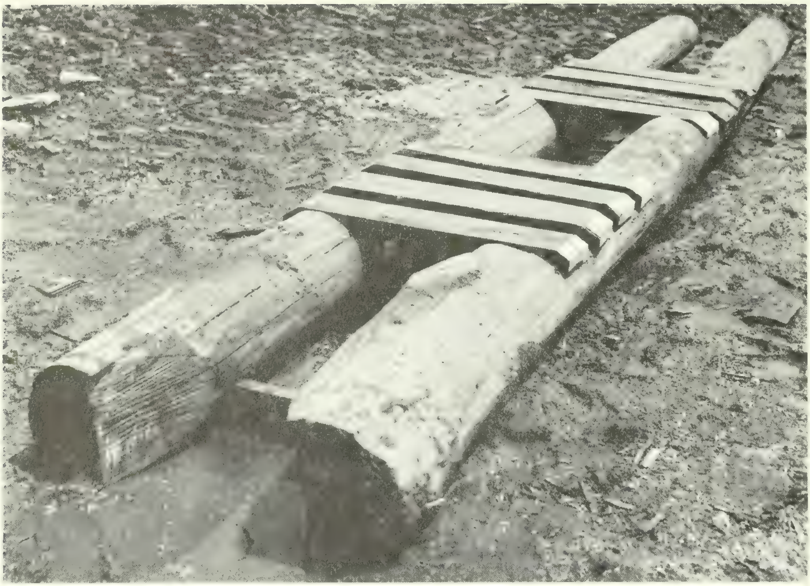


Figure 12.—This type of open-top culvert does not become plugged with debris as readily as ordinary open-top culverts, and the cost for materials is less. Note the spreaders on the bottom of the logs to prevent them from becoming squeezed together, and the 2-inch spaces between the boards to prevent water from running down wheel tracks and across the culvert. This same principle can be used to construct closed-top culverts.

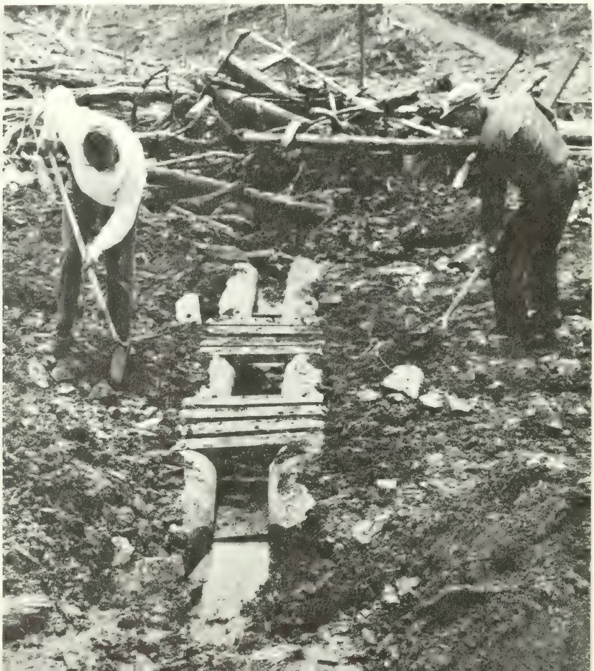


Figure 13.—Proper installation of culvert shown in figure 12.

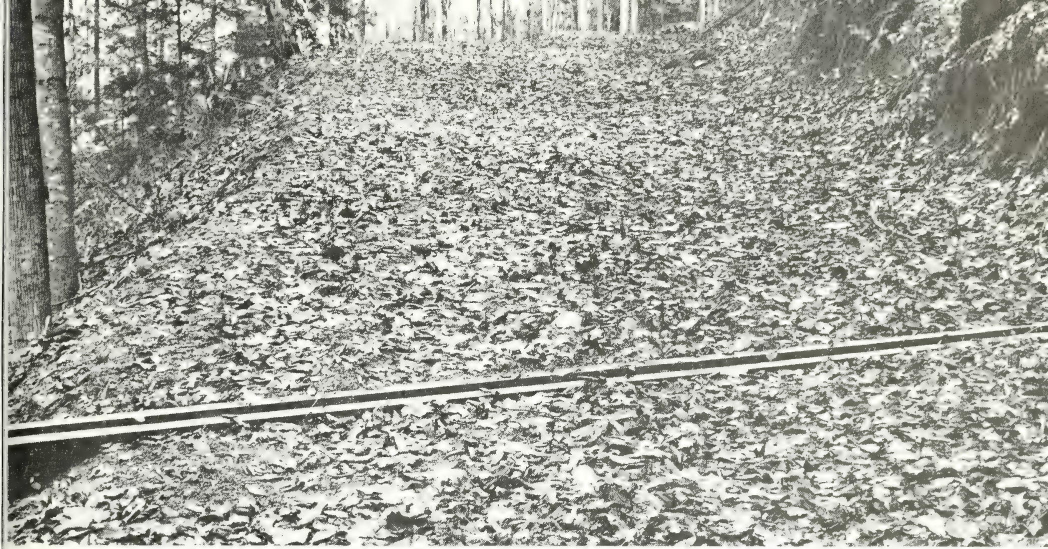


Figure 14.—Installing open-top culverts at about a 30-degree angle downslope enables them to clean themselves and makes them easier to cross with trucks, since both wheels do not cross at the same time. Note the outsloped road surface. A road properly maintained for intermittent travel can have this peaceful undisturbed appearance.

ineffective for erosion control on skidroads. They often become plugged with debris and must be cleaned frequently to be effective. Open-top culverts should be installed at a 30-degree angle downgrade (fig. 14).

Closed-top culverts are placed underneath road surfaces to drain ditches or small streams. They cannot intercept water flowing down road surfaces.

Although ditches are not normally used extensively on most logging roads, short ditches are often used to collect seeps and springs and drain them into culverts. Erosion can be prevented at culvert outlets by installing rocks for the culvert outflow to spill on.

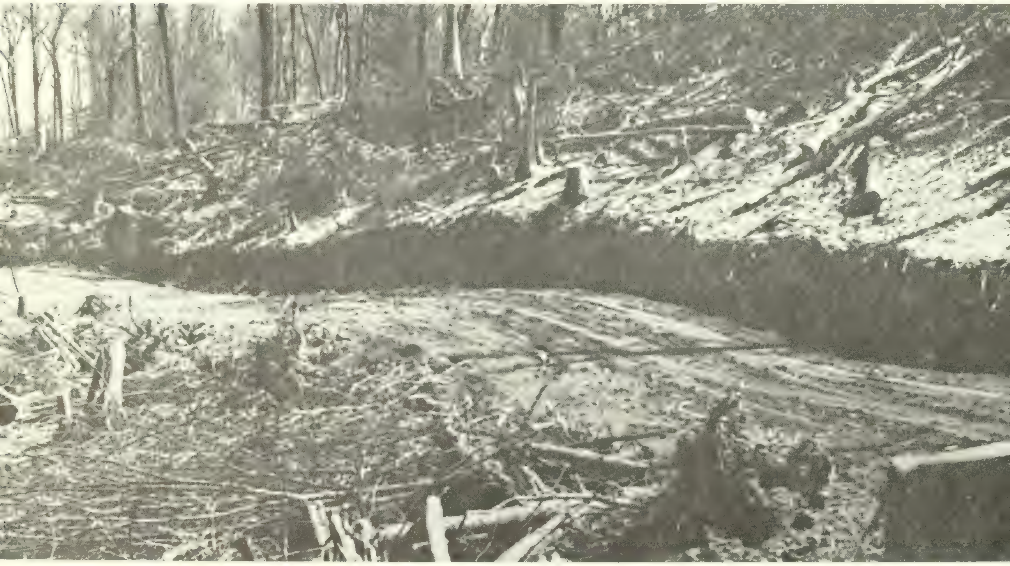
Outsloping

Outsloping is an effective way to remove small quantities of water from logging road surfaces. A properly outsloped road slants slightly from the cut bank to the outside edge of the roadbed (fig. 14). Both the surface and edge of the road must be smoothed out before outsloping can be effective. On logging roads this work is usually done with bulldozers. For safety, roads on steep terrain are often insloped during logging, then outsloped to about 3 percent after logging is completed.

Broad-Based Dips

Broad-based dips (figs. 15 and 16) can be used instead of culverts for cross drainage where no intermittent or permanent streams are present. They are installed after the basic roadbed has been constructed. Broad-based dips, when properly installed, are cheaper to maintain and more permanent than wooden culverts. They can be used effectively on both skidroads and truck roads when road grades do not exceed 10 percent. Broad-based dips do not increase wear on vehicles or reduce hauling speed when properly installed, and they have the added advantage of providing erosion control, even after intensive use, without much additional work. In addition, waterbars do not have to be installed on roads protected with a good system of broad-based dips. Future road

Figure 15.—Properly constructed broad-based drainage dips are cheaper to maintain and more permanent than wooden culverts.



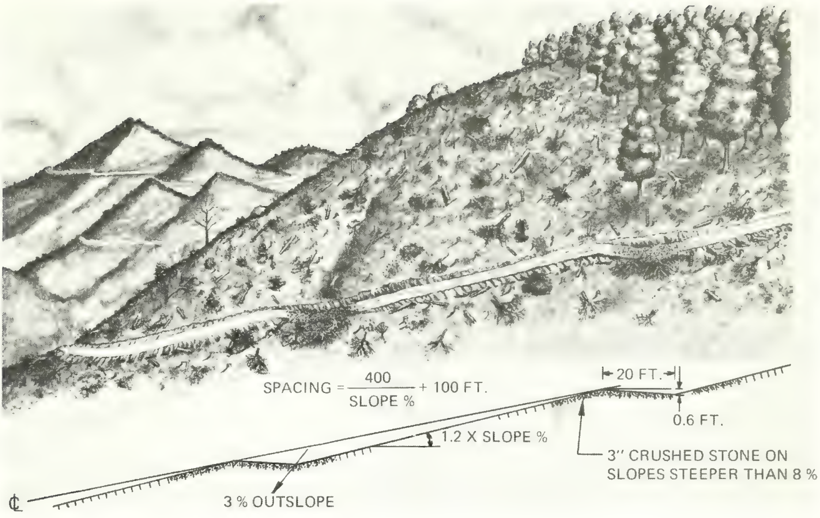

SPACING = 400/SLOPE % + 100 FT.
20 FT.
0.6 FT.
1.2 X SLOPE %
3" CRUSHED STONE ON SLOPES STEEPER THAN 8 %
3 % OUTSLOPE
℄

Figure 16.—Diagram showing how to construct a broad-based drainage dip properly. A broad-based drainage dip is constructed by building a 20-foot-long 3-percent reverse grade into the existing roadbed. The bottom of a broad-based drainage dip constructed in a roadbed having a 10-percent grade would be 2.6 feet below the original roadbed.

costs will be low when broad-based dips are used because the roadbed will not be damaged by erosion, waterbars will not have to be smoothed out, nor will rotted wooden culverts have to be replaced.

The biggest disadvantage of broad-based dips is that bulldozer operators must receive some preliminary training before they can construct them properly. Because of their many advantages over conventional wooden culverts, however, broad-based dips should be used more often on logging roads.

Broad-based dips are often made too small. A properly constructed broad-based drainage dip should be large enough so that logging trucks can be parked in it. The spacing formula (fig. 16):

$$\text{Spacing} = \frac{400}{\text{Slope }\%} + 100 \text{ feet}$$

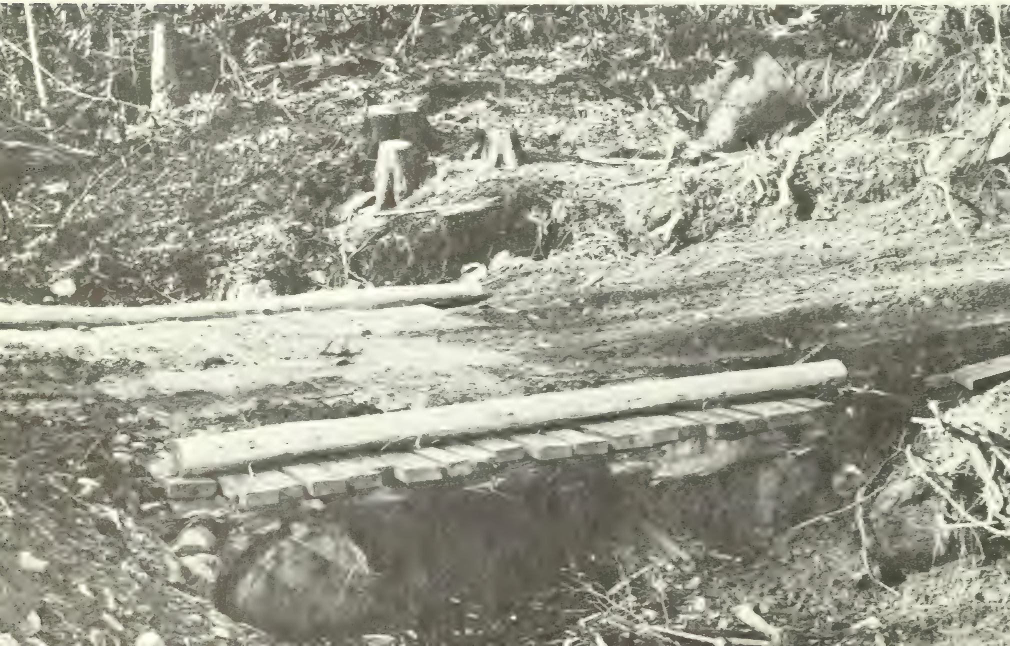
was used to derive the following tabulation, which can be used as a guide to determine spacing for broad-based dips and open-top culverts:

Road grade (percent)	*Spacing (feet)*
2 - 4	300 - 200
5 - 7	180 - 160
8 - 10	150 - 140

Crossing Streams

Bridges or fords should be used to cross streams too large to carry in culverts (fig. 17). Fords can be used where clean water is not a primary consideration and a firm rock base can be established on the streambed and on approaches to the ford. Bridges usually are best for crossing streams too large for culverts, but the final decision regarding the use of fords instead of bridges or culverts often is based on costs.

Figure 17.—A logging-road bridge, suitable for crossing small streams, made from low-grade hardwood lumber and nearby trees. This bridge easily supported a 15-ton bulldozer and will carry loaded logging trucks for several years.



All crossing sites should be selected at right angles to the stream and should not interfere with natural streamflow. Roads should climb away from stream crossings in both directions to prevent high water from running down roads because streams permitted to overflow onto logging roads can wash tremendous quantities of sediment into the streams in very short periods. Open-top culverts or dips on both sides of the crossing sites will divert road runoff into filter strips and prevent dirty water from running directly off roads into streams.

MAINTENANCE

Maintenance of logging roads is often neglected simply because logging with modern power equipment can be done without it. Nevertheless, even the most inexperienced logger knows that timber harvesting is easier and more profitable on smooth, mudfree roads.

Maintenance of logging roads to control erosion and to provide efficient access to stands is basically a problem of water control. The first requirement is a properly functioning drainage system in which culverts, dips, bridges, and outsloping are free to carry away water. The second requirement is to keep the road reasonably free of ruts, curbs, and logging debris that prevent water from flowing freely off road surfaces into drainage structures. All maintenance is reduced if, between the time of construction and heavy use, a few months are allowed for roads to settle.

To function properly, drainage structures must be maintained. They must be inspected frequently and repaired and cleaned whenever damaged or obstructed. Metal culverts require much less maintenance than wooden culverts. When installed on the proper gradient they will be largely self-cleaning and will require only occasional maintenance. An occasional plugged culvert may cause water to wash a gully across the road, but this small amount of erosion will not permanently damage the stream.

Most of the maintenance work required on wooden culverts and bridges can be done with hand tools. Bulldozer tracks are very damaging to wooden bridge surfaces and exposed wooden culverts; damage to these structures may be reduced by covering them with poles or slabs when bulldozers must cross them. Broad-based dips should be reshaped whenever roads are graded. Road surfaces are usually reshaped with bulldozers, which are better than graders to reshape dips. This work is best done a few days after heavy rains, when soil still is soft but not yet too hard and dry to work easily.

Often it helps to "daylight" heavily shaded roads by cutting away overhanging trees because roads exposed to sun and wind dry quickly and require least maintenance. Such treatment is usually restricted to main access roads and roads intensively maintained for wildlife.

Careful location completely eliminates many road-maintenance problems and minimizes others. For instance, experience has shown that roads on sunny south and west slopes dry faster than those on shadier north and east slopes. Roads upslope from streams, springs, or seeps avoid not only the initial expense of many drainage structures but also the frequently recurring expense of cleaning and reshaping surfaces built of soft, slowly draining soil. On the other hand, slumping banks and washouts often create maintenance problems on roads along overly steep slopes.

TRAFFIC REGULATION

Regulating traffic on logging roads during unfavorable weather is an important phase of erosion control. It is impossible to control erosion if unsurfaced roads are used during excessively wet weather. Logging under these conditions destroys drainage structures, plugs up culverts, and causes excessive rutting; thus logging costs are greatly increased (fig. 18). During wet weather the costs of inefficient logging, combined with damage to roads, streams, and wildlife, may exceed the value of timber harvested.

Regulating traffic to minimize the time roads are used intensively helps reduce erosion risks. This is best done by completing logging operations on each area as quickly as practical. When possible, remote areas should be logged first, and measures designed to insure erosion control after logging should be installed

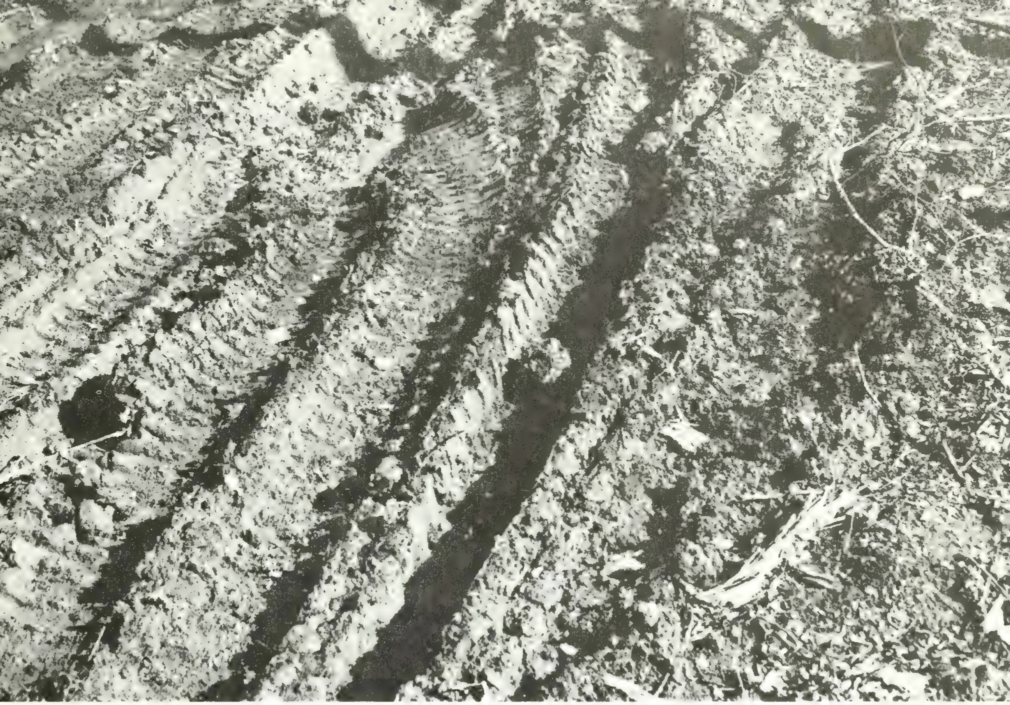


Figure 18.—Severe rutting caused by logging during unfavorable weather. This damage usually occurs during winter and spring months but can occur any time soils become waterlogged.

as the logging operation progresses. Problem areas such as steep roads, wet areas, and highly erodible soils should be logged during the most favorable logging weather. In this way, the most erodible roads can be put to rest before erosion begins.

Sometimes it is not practical to apply this type of common-sense management. For example, loggers might not be able to afford the higher initial road costs that are usually required to operate remote areas first, but hauling forest products for long distances over logging roads during marginal logging weather can unnecessarily rut and otherwise damage soft, wet, thawing roads. Under these restrictive conditions, most loggers will try to operate as close as possible to an all-weather road.

If possible, timber owners and loggers should agree to restrict the actual skidding and hauling of wood products to frozen roads or roads dry enough to permit skidding and hauling without seriously rutting road surfaces. Many mills stockpile logs in the fall and early winter, expecting to shut down logging operations during bad weather. In many cases, stockpiling logs to last an additional month would permit hauling to be limited to good weather without mill shutdowns.

CARE AFTER LOGGING

Immediately after hauling and skidding are completed, additional protection against erosion should be provided. If there are plans to use truck roads intermittently after logging, culverts and bridges can be left intact. Periodic maintenance of drainage structures will permit intermittent use of roads during dry weather and preserve them for future intensive use. If there are no plans to use truck roads after logging, wooden culverts and bridges can be removed to restore natural drainage. Streambanks are disturbed least if bridge abutments are left intact. Removing bridge planking is an effective way to close roads to all but foot traffic.

Sometimes culverts are removed from deep fills for use in other roads or in an attempt to restore natural drainage. However, the cost of removing them can easily exceed their market value and they are usually damaged by machinery during extraction. Also, the disturbance created when culverts are removed often presents an unsightly appearance. Though culverts may eventually become plugged and cause an erosion problem, a greater problem occurs when these high banks of loose fill are undercut by unconfined water and erode for years directly into the streams. Ordinarily, culverts should be left when there is more than 2 feet of fill over them.

When logging is completed, the surfaces of all logging roads should be smoothed, outsloped about 3 percent; and drainage structures should be cleaned. Broad-based dips and culverts, when properly maintained, will provide adequate erosion control on roads where intermittent use is expected after logging. Waterbars should be installed on logging roads that will be closed to vehicle travel after logging and that lack an adequate system of broad-based dips. Waterbars should be installed on the most heavily used skidroads. Logging slash can be lopped and scattered on roads to supplement waterbars where the erosion hazard is high. The following tabulation can be used as a guide to determine waterbar spacing:

Road grade (percent)	*Distance between waterbars (feet)*
2	250
5	135
10	80
15	60
20	45
25	40
30	35

Waterbars, like culverts, should be installed at about a 30-degree angle downslope to help turn water off roads. The downhill end of a waterbar must be open to prevent water from accumulating behind it.

Waterbars can be constructed with hand tools, but bulldozers are commonly used (figs. 19 and 20). When waterbars are con-

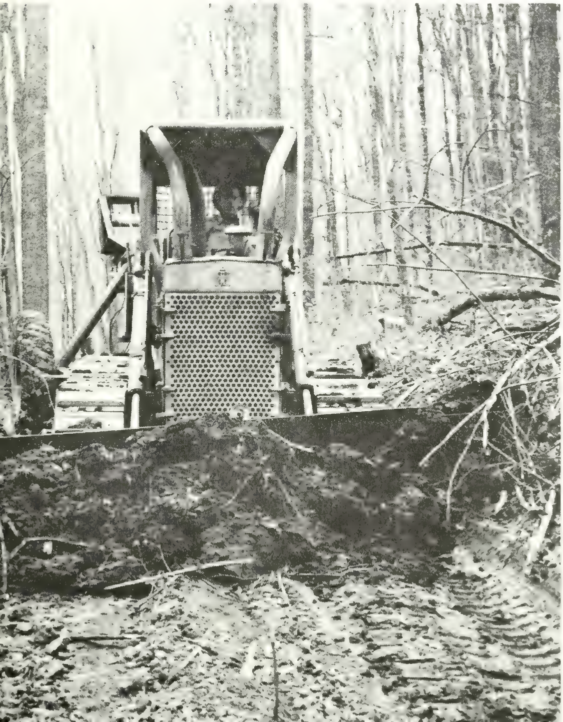


Figure 19. — Waterbars being installed on a logging road to be closed to all vehicle traffic.

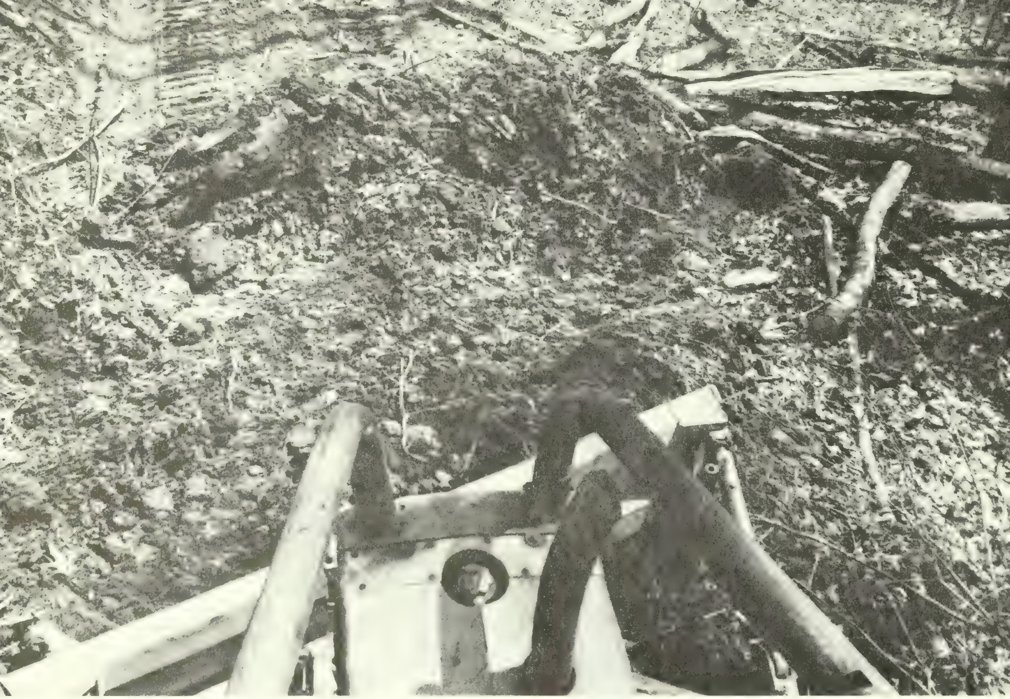


Figure 20.—A properly constructed waterbar.

structed by machine, it is best to start at the end of the road and work out so that waterbars are not damaged by frequent crossing with machinery.

SEEDING

Grass seeding is an important supplement to mechanical erosion-control structures on logging roads (fig. 21). Seeding is also beneficial in that it provides food for wildlife and improves the appearance of logged areas. However, seeding is usually restricted to areas with high erosion hazards and roads where grass can be maintained for wildlife. In the Appalachian Mountains, most logging roads will revegetate naturally within 2 years if mechanical erosion-control measures are adequate.

One mile of logging road 12 feet wide will contain about 1½ acres of seedable soil. The planting surface should be prepared by disking in 2 tons of lime and 500 pounds of 5-20-10 fertilizer

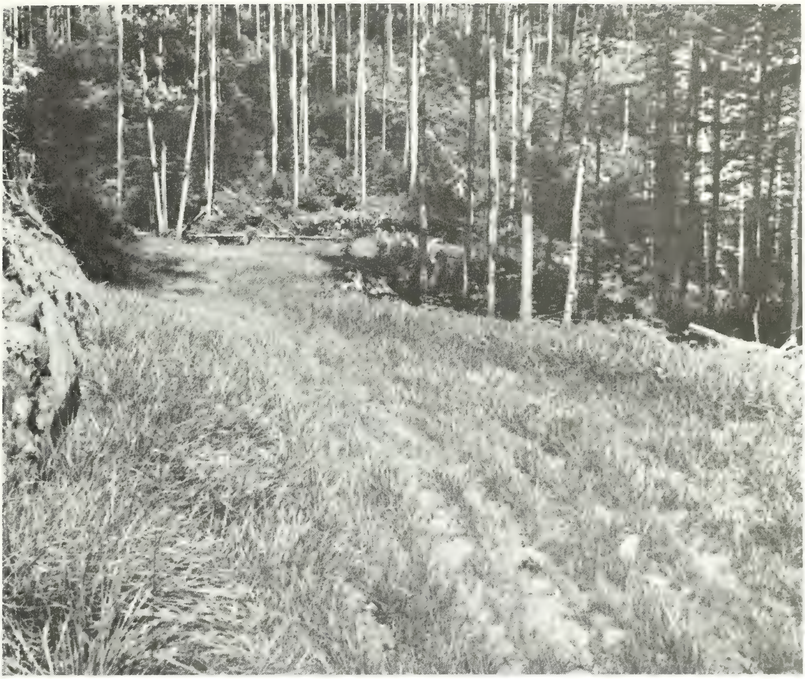


Figure 21.—Seeded logging roads help control erosion.

per acre. A mixture of 2 pounds of ladino clover and 12 pounds of Kentucky fescue per acre has been successful in the Monongahela National Forest in West Virginia, but the best seed mixture and application procedure must be determined for each locality. Service foresters, county agents, or soil conservation personnel can provide landowners with helpful suggestions for most localities.

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ACKNOWLEDGMENT

The author has drawn freely from the publications listed. The reader is urged to consult these publications if detailed information beyond the scope of this publication is desired. When needed, help and advice with road problems can be obtained from qualified personnel such as service foresters and consulting foresters.

THE FOREST SERVICE of the U. S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

by Denver P. Burns

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NORTHEASTERN FOREST EXPERIMENT STATION, UPPER DARBY, PA.
FOREST SERVICE, U. S. DEPARTMENT OF AGRICULTURE
RICHARD D. LANE, DIRECTOR

THE AUTHOR

DENVER P. BURNS, entomologist, received his B.S. degree in agriculture (1962) and M.S. (1964) and Ph.D. (1967) degrees in entomology at The Ohio State University. He joined the U. S. Forest Service in 1962 and has specialized in the biology and ecology of hardwood insects. Currently stationed at Delaware, Ohio, he is a member of the Northeastern Forest Experiment Station project conducting research into the biology and behavior of insects affecting hardwood quality.

YELLOW-POPLAR, like the other desirable hardwoods, is attacked by a variety of insects. However, only four species of insects are considered economically important: the tuliptree scale, the yellow-poplar weevil, the root-collar borer, and the Columbian timber beetle. These are native enemies of yellow-poplar *(Liriodendron tulipifera* L.) wherever the tree grows.

THE TULIPTREE SCALE

{*Toumeyella liriodendri* (Gemlin)}

This sucking insect has been considered more a nuisance than a serious pest of yellow-poplar. However, research recently conducted by the author and Dr. David E. Donley demonstrates that this insect is often responsible for the failure of yellow-poplar to regenerate successfully on old-field sites.

The scale damages its host by removing large quantities of phloem sap (fig. 1). It can be found on yellow-poplars of any size, but it damages seedlings and saplings most severely. It feeds

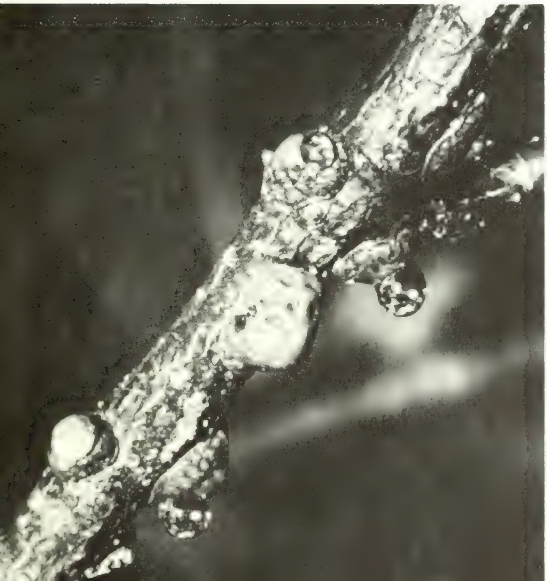


Figure 1.—Female tuliptree scales excreting honeydew. The honeydew is composed of phloem sap and metabolic products on the scale.

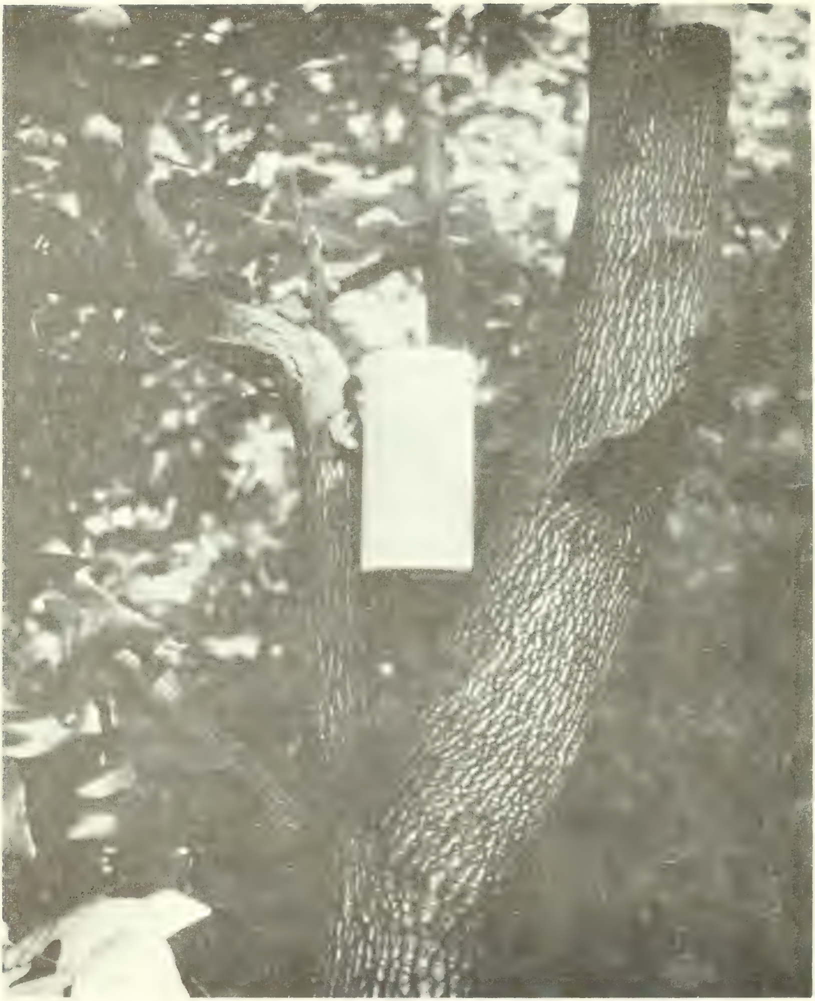


Figure 2.—A crook on a yellow-poplar tree, caused by scale attack. The carton is 8 inches tall.

on twigs and stems less than 1.2 cm in diameter, and on adventitious twigs and callus wound tissue.

The scale causes four kinds of injury. It can kill the tree. You rarely notice attacks for only 1 year that can kill 2-, 3-, and 4-year-old seedlings. Death of the tree is more striking when older trees are killed as the result of severe scale attacks for two or more consecutive years. Trees more than 10 inches d.b.h. have been killed by the scale. Basal sprouts often develop when saplings are killed, but they in turn are attacked by the scale and die within a few years.

Scale attack often kills the leader, and one or more of the lateral branches assume apical dominance. This results in a crook at the junction of the lateral branch and the stem (fig. 2), or a double top. The crooks may disappear as the tree trunks increase in diameter, or they may persist as a permanent defect.

The third kind of damage occurs when the leader and upper laterals are killed so that no lateral branch assumes dominance. When this happens, the tree becomes bushy and may survive until overtopped by its competitors.

The most subtle expression of damage is the loss of vigor. Symptoms of vigor loss become visible when the lower branches of open-grown yellow-poplars blacken and die and the foliage of the upper crown becomes thin and sparse (fig. 3). The leaves and trunk of the tree usually become black with sooty mold growing on the honeydew. The premature pruning of the lower branches would be desirable except that the tree often dies or adventitious growth occurs.

The scale has one generation per year *(Burns and Donley 1970)*. From mid-August until first frost the females give birth to tiny crawlers, the motile stage of the insect. The crawlers walk over the bark and either stick their mouthparts into the tree or walk onto the leaves. The scale spreads from tree to tree when crawlers on the leaves let go and are blown about.

Once the mouthparts are inserted into the tree, the crawler cannot remove them. The crawler molts within a few weeks to the second instar or overwintering stage. The size of a pinhead, and charcoal-colored, it is found on the undersides of twigs and other protected locations.

In spring the scales begin to grow and excrete honeydew. The males pupate under an opaque whitish cover in late May. The cover is easily seen and remains on the tree for several months after the males emerge and mate with the females in mid-June.

Growth of the females continues into August, when they mature and produce crawlers, thus completing the life cycle.

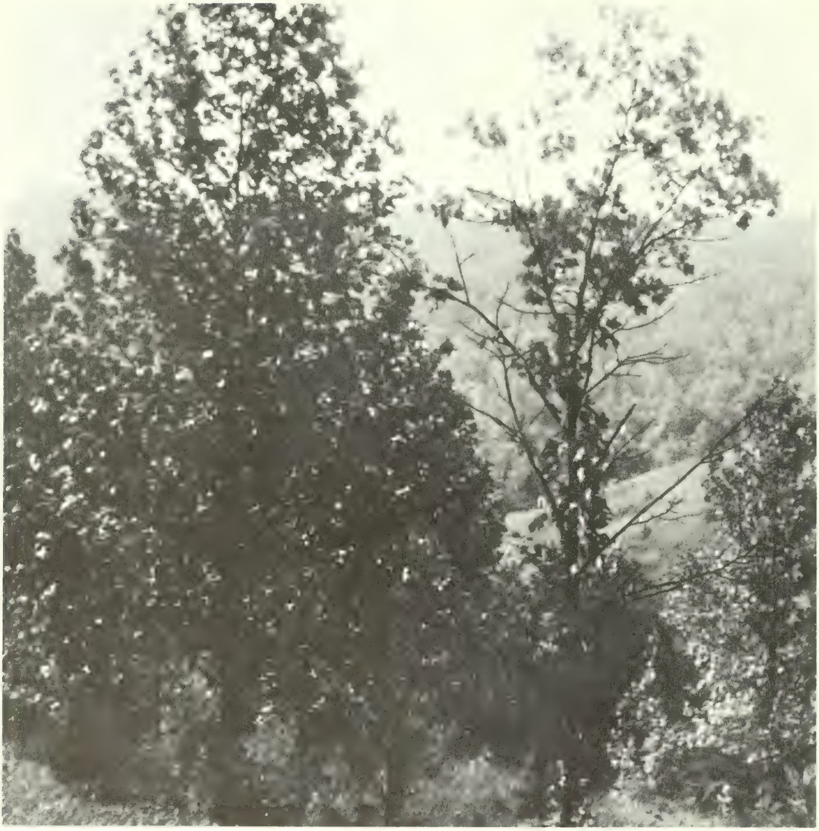


Figure 3.—The tree on the left has typical form for open-grown yellow-poplar. The tree on the right has been repeatedly attacked by scale. Note the sparse foliage, numerous dead twigs, and the stub of the broken-off second stem.

Many insects collect tuliptree scale honeydew and use it for food *(Krombein 1951; Burns 1964)*. Some species of ants are numerous and active when collecting honeydew and their activity disrupts or prevents the feeding or egg-laying of parasites and predators of the scale. Thus the presence of some species of ants allows scale populations to remain at high levels for several years so that the host trees are killed or seriously damaged. When ants are not present, parasites and predators generally are effective control agents.

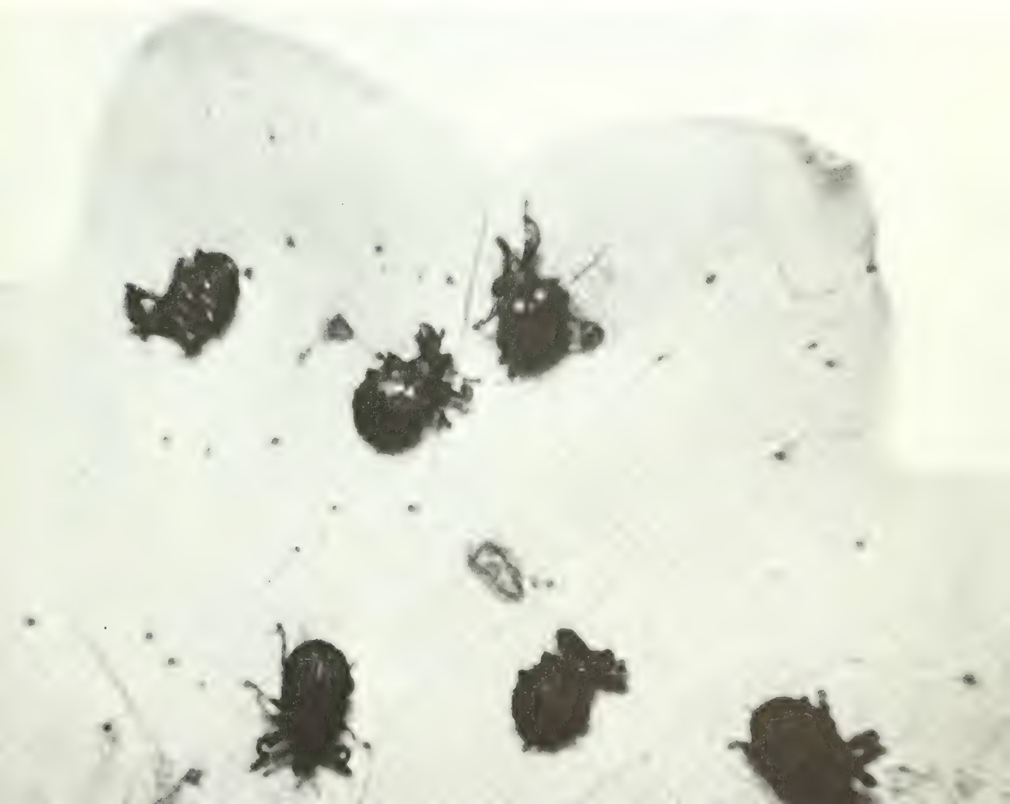
THE YELLOW-POPLAR WEEVIL

[*Odontopus calceatus* Say]

This defoliator is a small blackish beetle that feeds on buds and foliage. In its larval stages, it mines the leaves of yellow-poplar, sassafras, and magnolia (fig. 4). It has been observed since the mid-1880's but was not considered a serious pest of yellow-poplar until 1960.

In 1960, yellow-poplar was attacked over large areas of Appalachia; the most severe infestation centered in eastern Kentucky. The beetle has been abundant each subsequent year except 1963 and 1966. The infestation in 1965 was centered along the Ohio River from Cincinnati eastward. In 1966, two severe frosts killed most of the larvae; but by July 1967 the population level was again high.

Figure 4.—Adult yellow-poplar weevils.



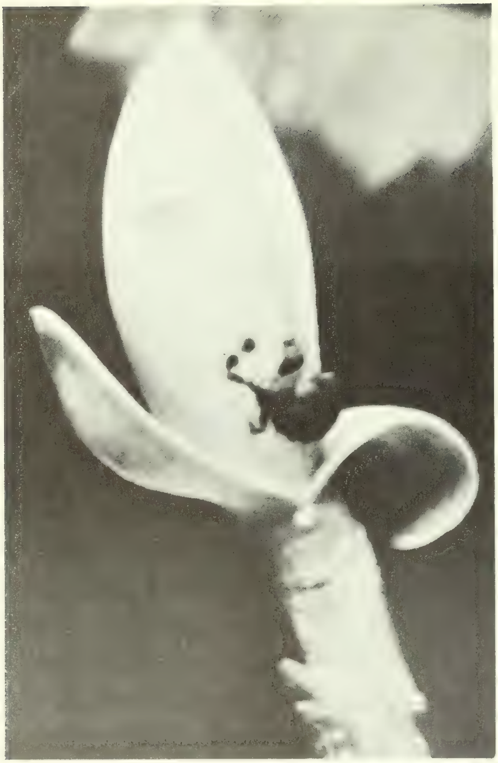


Figure 5.—Adult weevil and feeding punctures in bud.

The weevil has one generation per year throughout the Ohio River Valley *(Burns and Gibson 1968)*. Adults overwinter in leaf litter. On warm days in late April and early May in the latitude of southern Ohio and Pennsylvania the weevils begin to feed. In Florida and Mississippi, adults have been taken in late February. Before bud break, the weevils attack the swelling buds and make puncture-like feeding marks (fig. 5). They also attack the stipules. As the leaves unfold and enlarge, the insects feed upon them too. Rice-shaped holes in the leaves, about 1/6 inch in diameter, result when the adult weevils puncture the buds or feed from the undersurface of the leaves.

Mating and oviposition occur in May and early June. The eggs are placed in a 1/4 inch section of the midrib on the underside of the leaves. The midrib is partially or wholly destroyed by the oviposition and breaks over. As the newly hatched larvae move from the midrib into the mesophyll, their boring action accentuates the midrib damage.

The larvae commonly feed side by side in one or two groups in a communal mine. Occasionally a leaf contains two mines. If the two mines are on one side of the midrib, only one mine is extensive; however, if the mines are on opposite sides of the midrib, both mines usually develop normally. Each mine may contain 1 to 19 larvae. The mined portion of the leaf inflates and the tissues become dry. As the larvae grow and extend the mines, they extrude continuous filaments of dark fecal material; and the filaments are more conspicuous than the larvae when the mines are opened.

When ready to pupate, the larvae move to an inflated portion of the mine and spin spherical silk cocoons. The length of the pupal stage, as well as the length of the other stages, appears to depend on the weather. In southwestern Pennsylvania the first adults emerge from leaves in early June.

The newly emerged weevils feed on the foliage. Sometimes they chew through the leaves, but more often they remove only the lower epidermis and mesophyll, leaving the upper epidermis intact (fig. 6). This feeding produces numerous chlorotic spots

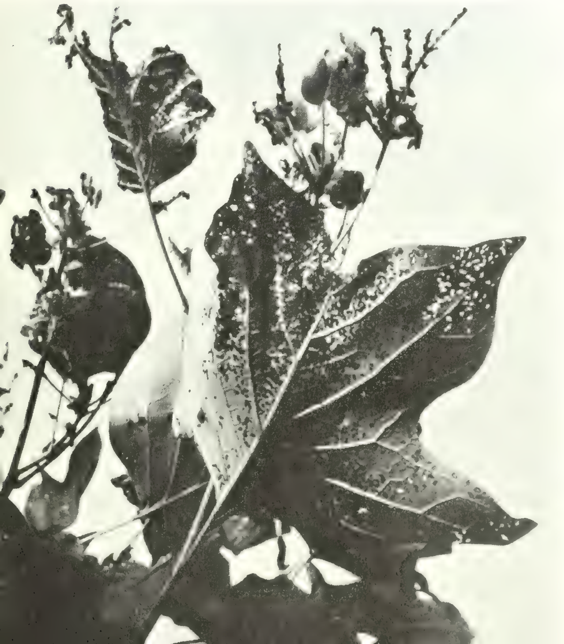


Figure 6.—Weevil injury to yellow-poplar leaves.

and results in the burned appearance of severely attacked trees. Feeding by the newly emerged weevils causes the most extensive damage to the host.

By mid-July most of the adults have entered a period of aestivation, which is continuous with diapause during the winter. Only a few weevils are active in August.

There is no effective control measure known for the yellow-poplar weevil other than chemical sprays for the adults. Parasitism of the immature stages has occurred at rates up to 50 percent but has not prevented continued large populations. The factors that have allowed this insect to become a pest since 1960 have not been identified.

THE ROOT-COLLAR BORER

[*Euzophera ostricolorella* Hulst]

Tulip-poplar borer and tulip bark borer are other common names for this insect. This pest is the larva of a moth. The larva bores in the phloem tissue at the base of yellow-poplar trees. Attacks are confined mostly to an area from 2 feet above the soil line to 2 inches below. Fewer than 10 percent of the attacks observed by Hay *(1958)* were between 2 and 10 feet above the ground. He indicated that trees over 10 inches d.b.h. receive most attacks, but occasionally a tree as small as 6 inches d.b.h. is infested.

The borer attacks are not generally serious by themselves, but they permit the entry of stain organisms or, more serious, they provide entry points for rots or other pathogens or for carpenter ants. The bark at the base of an infested tree often appears loose, and exit holes are visible in the bark. In 1954, near Lamasco, Kentucky, many trees were killed or dying as a result of root-collar borer attacks and/or introduced pathogens. In northern Indiana, trees infested with the root-collar borer have shown considerable dieback and mortality *(Schuder and Giese 1962)*.

The adult moths first appear in June and in lesser numbers in September and October, indicating a partial second generation.

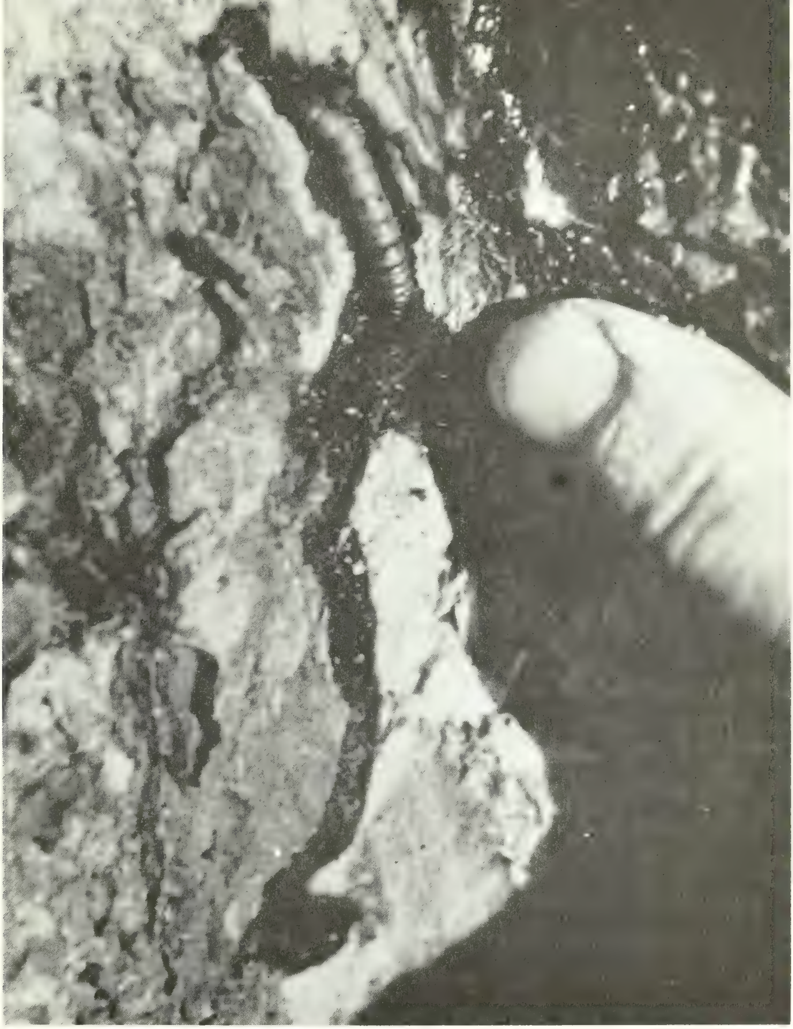


Figure 7.—Mature larva of the root-collar borer. The larva first bored down 3 inches, then reversed direction and was extending its tunnel upward.

The adult is a dark gray moth with a slightly reddish wing base. It is about 1¼ inches long. Egg-laying has not been observed, but the eggs are probably laid in crevices of the bark. The larvae bore into the phloem and make a vertical tunnel about 4 inches long and a ¼ inch in diameter (fig. 7). The tunnel surfaces are stained black, and watery black frass may ooze from the entrance hole.

In late summer, pupation occurs in a cocoon spun in the tunnel. The adult either emerges as part of the second or fall generation, or overwinters and emerges the following spring. Apparently there are Dipterous and Hymenopterous parasites of the larvae, as evidenced by pupal cases in the borer tunnels, but none has been reared and identified. Woodpecker activity was noticeable on nearly every borer-infested yellow-poplar in the 1954 Kentucky infestation. Only small-scale control tests with insecticides have been made.

THE COLUMBIAN TIMBER BEETLE

[*Corthylus columbianus* Hopkins]

This beetle is a pest of many hardwoods in addition to yellow-poplar. Damage to lumber by this insect is variously called "flagworm", "spotworm", "patchworm", "black holes", "steam boats", and "pinhole damage". In yellow-poplar the defect is called "calico poplar" (fig. 8). Attacks by the beetle do not kill the host, but the defects may seriously degrade the wood from what appears to be a sound tree.

The Columbian timber beetle has at least one generation per year and may have two or more depending on the host and geographical location. The beetles overwinter as adults or pupae in the tree in which they were reared. Some adults may go to another tree, bore a simple gallery, and overwinter in it.

In May the beetles emerge and attack new trees or reattack their host trees. Most attacks occur the lower 6 feet of the bole. Attacks are marked by small damp spots and fine white dust from the boring. The adults excavate a main gallery directly into the sapwood. A secondary gallery may branch off to either side. The main gallery is about 1/16 inch in diameter and a few inches long. The secondary galleries are the same diameter but are shorter. Niches or egg cradles are bored at right angles to the galleries. Most of the niches extend upward, although a few extend downward. The galleries, niches, and a stain that is always associated with them degrade the wood.

After the niches are constructed, mating occurs within the

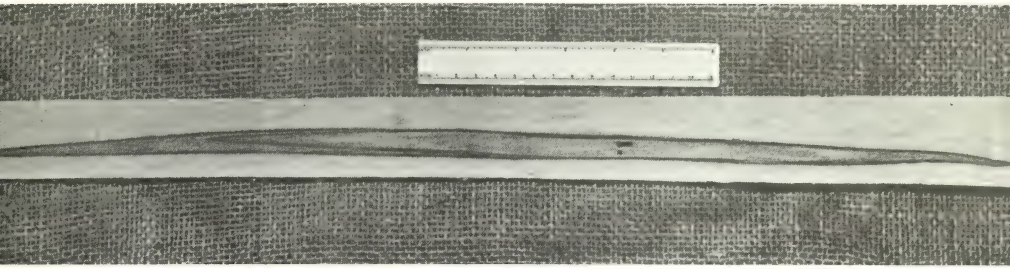


Figure 8.—"Calico poplar", the stain defect associated with Columbian timber beetle attack in yellow-poplar, is shown here in profile in a piece of rotary cut veneer. A gallery in cross-section and an egg niche are also visible. The ruler is 6 inches long.

gallery. The female lays an egg in each niche then plugs the niche with frass. The eggs hatch within 6 days, and the larvae mature in about 2 weeks. Symbiotic fungi and yeasts growing on the walls of the niches serve as food for the larvae. Pupation requires 8 or 9 days and occurs in the niche, with the head of the pupa oriented towards the plug. The life cycle can be completed within 4 weeks.

No satisfactory control measures for this insect are known.

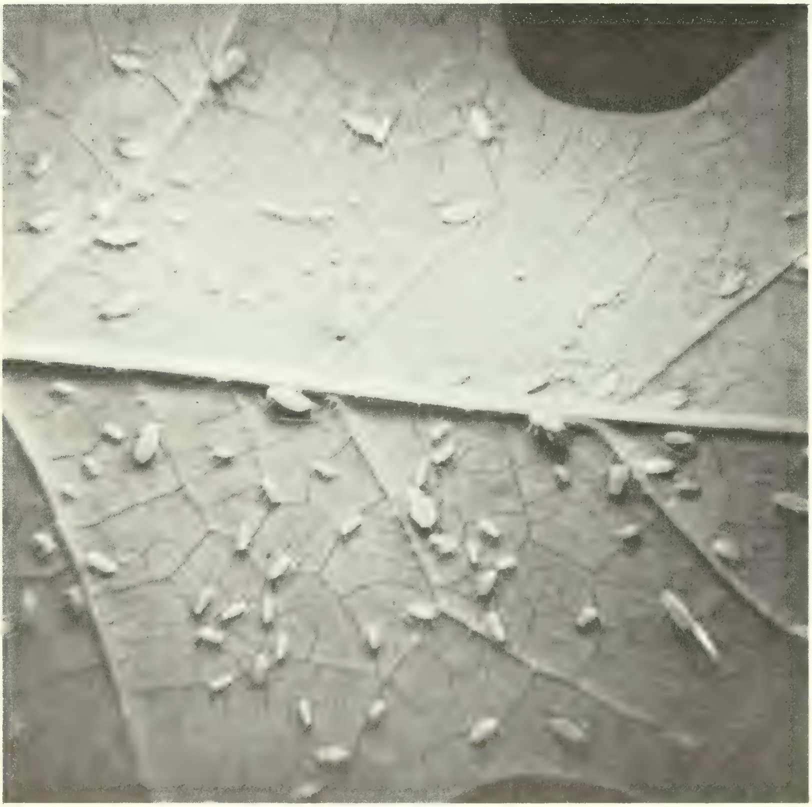
OCCASIONAL PESTS

Yellow-poplar has been reported as a host for more than 100 species of insects. Some of them cause observable damage when they are abundant. In addition, many insects are found on and in the vicinity of yellow-poplars infested with tuliptree scales. Flies, bees, and wasps particularly are attracted to the honeydew, to other insects attracted to the honeydew, or to the dead twigs killed by the scale.

The tuliptree aphid *Macrosiphon liriodendri* Mon. is often found feeding on the undersides of the leaves (fig. 9). It is a large pale-green aphid that seldom is found in great numbers. When it is abundant, the foliage becomes pale and will fall prematurely *(McCarthy 1933).*

The tulip gall fly *Thecodoplosis liriodendri* (O.S.) produces

Figure 9.—The Tuliptree aphid *Macrosiphon liriodendri* Mon. on the underside of a yellow-poplar leaf.



½-inch wide greenish-yellow or greenish-brown spots or blisters on the leaves. Several species of fungi also cause leaf spot in yellow-poplar. Only the insect-caused spots have a hollow area beneath the upper surface of the leaf. This is the mine chewed by the immature (maggot) stage of the fly. Doane and others (1936) reported that this insect is often abundant enough to do considerable damage in the South.

The larvae of the tulip tent maker moth *Polychrosis liriodendran* Kearfott occasionally defoliate yellow-poplars. The larva constructs a small web on the underside of the leaf, usually near the midrib, and skeletonizes part of the leaf. As the leaf is skeletonized, it is folded together and held with silk. Defoliation by this insect is very localized: only a few trees are noticeably attacked in a given area.

Larvae of two species of the giant silkworm moths feed on yellow-poplar foliage, consuming most or all of the leaf blades. They are the spice-bush silk moth *Callosamia promethea* (Drury) *(Craighead 1950)* and the tuliptree silk moth *C. angulifera* Walker *(Herrick 1935)*. The larvae of both species reach 2 inches in length. The larva of *C. promethea* has coral-red tubercles or stalks on the second and third anterior segments; these stalks show conspicuously against the bluish-green epidermis. These insects overwinter as pupae in brown cocoons dangling from yellow-poplar twigs. The cocoon is formed in a leaf, which is prevented from falling off the twig by the petiole of the leaf being securely fastened with silk. Most cocoons of *C. angulifera* fall to the ground.

Another moth larva that occasionally defoliates yellow-poplar is the tuliptree beauty *Epimecis virginaria* form *carbonaria* Haim. This is one of the Geometridae, the measuring worms. The larvae are about 1½ inches long, and they are stout when fully grown. The head capsule is small and reddish-brown; the body is yellowish to dark brown, marked with many fine, irregular, wavy, longitudinal, pale yellowish lines. The underside and legs are yellowish to light brown. The larvae are active from May through July. The larvae migrate to the ground during the day and climb trees to feed at night. Pupation occurs in the ground, and the pupa is the overwintering stage.

Occasionally yellow-poplar twigs about ½ inch in diameter are slit or torn along the branch axis with clumps of wood fibers protruding from the wound (fig. 10). These are egg-laying sites of the periodical cicadas or "17-year locusts" of the genus *Magicicada*. Many of the wounded twigs break over and die.

The adult cicadas are present from late May through June. They are smaller than the dog-day cicada and have reddish eyes, wing veins, and legs. Eggs placed in the slits hatch in 6 to 8 weeks, and the emerging nymphs immediately drop to the ground and burrow into the soil. When they find suitable roots they begin to suck the sap. This continues for 13 or 17 years depending on

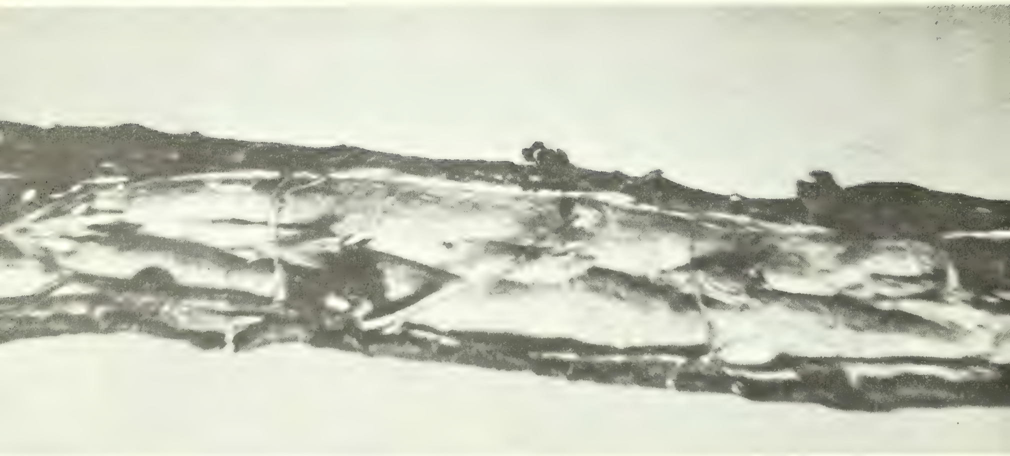


Figure 10.—This torn yellow-poplar twig was used as an egg-laying site by periodic cicadas.

the species and location. When feeding is completed, the nymphs emerge from the ground, climb vertical objects, and attach themselves; then they molt to the adult stage. There is no economical way to protect stands of yellow-poplar from this insect.

Several species of armored scales occasionally attack yellow-poplar twigs and small branches. They include the willow scurfy scale, *Chionaspis salicis-nigrae* (Walsh) *(Craighead 1950);* and oystershell scale, *Aspidiotus ulmi* Johns *(Westcott 1946).* And in Florida, Dekle *(1965)* reported he found three armored scales infesting yellow-poplar: the coconut scale, *Aspidiotus destructor* Sign.; the Harper scale, *Neopinnaspis harperi* McKenzie; and the walnut scale, *Aspidiotus juglans-reginae* Comst.

Careful examination of the twigs is necessary to find these scales—even when they are abundant. A hand lens is particularly useful. When abundant, these insects can stunt or kill twigs and small branches.

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THE FOREST SERVICE of the U. S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

Distribution of DIAMETER GROWTH RATES & CLEAR STEM LENGTHS *as a Basis for Selecting* SUPERIOR PHENOTYPES

CLEMSON UNIV
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SCI. TECH. & AGR. D

**by George R. Trimble, Jr.
and Donald W. Seegrist**

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NORTHEASTERN FOREST EXPERIMENT STATION, UPPER DARBY, PA.
FOREST SERVICE, U. S. DEPARTMENT OF AGRICULTURE
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THE FIRST STEP in obtaining stock for developing seed orchards of superior genotypes is to select superior phenotypes, or plus trees. These plus trees may be chosen for their superiority in a single characteristic, or for their high ratings in a combination of characteristics.

A candidate plus tree is usually chosen tentatively for the good appearance of its features of interest. It is carefully measured for these features. After that, a number of nearby trees of the same species, age, and crown class—usually three to five if available—are measured and compared to the candidate tree. If the candidate tree rates sufficiently better than the comparison trees, then it is classed as a superior phenotype, acceptable for inclusion in the tree-selection program.

There are a number of variations to this procedure, which range from simply selecting trees that look good to methods that include weighing a large number of features desired in a tree and rating the candidate tree against the weighted measurements from several comparison trees. The cost of selecting plus trees goes up as the number of measured characteristics increases and in proportion to the number of comparison trees used. But aside from its cost, the system of using comparison trees involves another serious drawback. If there are no suitable comparison trees nearby, as is often the case, there is no yardstick for judging the candidate tree; and thus superior trees may be passed up.

If we knew how the features of interest were distributed in the tree population, we could set any level we wished as the criterion for a plus tree without the need to measure comparison trees. For example, if we were interested in high diameter growth rates, we could select trees with growth rates in the upper percentiles of the distribution for a given site index.

Other desirable characteristics could be considered in the same way; however, when we select for more than one characteristic, we must consider the joint distribution of the variables in the tree population. For instance, this paper presents the joint distribution of diameter growth and length of clear stem for northern red oak (*Quercus rubra* L.). These data could be used in an actual tree-selection program for this species.

GROWTH RATES

Not only is fast diameter growth desirable, but also there is reason to believe that increased growth in red oak can be effected through selective intraspecific breeding.[1]

The distribution of d.b.h. growth rates (i.b.) was based on 292 sample trees measured in a site study (*Trimble and Weitzman 1956*) made in even-aged, unmanaged, well-stocked stands in north-central West Virginia and western Maryland. These trees were of dominant and codominant crown classes—the classes from which plus trees are customarily selected—and were stratified by oak site-index classes (*Schnur 1937*). The trees included in the growth distribution were restricted to between 40 and 70 years of age because: (1) within this range in red oak, age probably has little effect on d.b.h. growth rates; (2) site differences are clearly expressed; and (3) the point at which the clear stem breaks up into the crown is well established (*Trimble and Weitzman 1956*).

Ten-year diameter growth rates, measured on increment-borer cores to the nearest even 1/10 inch, were chosen as criteria rather than 20-year rates or average growth over the tree's age, because it was thought that the shorter-growth period better reflected tree and stand conditions at the time of tree selection.

The distribution of diameter growth rates is given by 10-foot site-index classes: 60—a fair site (table 1); 70—a good site

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[1] Schreiner, Ernst J. Forest Tree Improvement Research. Unpublished problem analysis, Northeastern Forest Experiment Station.

Table 1. — Number of trees by diameter growth rate and length of clear stem; northern red oak, site index 60

Clear stem length (feet)	10-year d.b.h. growth (i.b.), in inches										Total	
	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	Frequency	Percentile
13	—	—	—	—	—	—	1	—	—	—	1	1.8
16	—	—	—	—	—	—	—	1	—	—	1	3.6
18	—	—	—	1	—	—	—	—	—	—	1	5.4
21	—	—	—	1	1	—	—	—	—	—	2	8.9
22	—	—	—	1	—	1	—	—	1	1	4	16.1
23	—	—	1	—	—	—	—	—	—	—	1	17.9
24	—	1	—	—	1	—	1	—	—	—	3	23.2
25	1	—	—	1	—	1	—	1	—	—	4	30.4
26	—	—	1	2	—	—	—	—	—	—	3	35.7
27	1	—	—	—	—	—	—	—	1	—	2	39.3
28	—	1	—	1	1	—	—	1	1	—	5	48.2
29	—	—	—	—	—	1	—	—	—	—	1	50.0
30	—	—	—	1	—	1	2	—	1	—	5	58.9
31	—	—	—	—	1	1	—	—	—	1	3	64.3
32	1	—	2	—	—	2	—	—	—	2	7	76.8
33	—	1	1	—	—	—	—	—	—	—	2	80.4
34	—	—	—	—	—	1	—	—	—	—	1	82.1
35	1	—	—	—	—	1	—	1	—	—	3	87.5
36	—	—	1	—	—	—	—	—	—	—	1	89.3
37	—	—	—	1	—	—	—	—	—	1	2	92.4
38	1	—	—	2	—	—	—	—	—	—	3	98.2
39	—	—	—	—	—	—	1	—	—	—	1	100.0
Frequency	5	3	6	11	4	9	5	4	4	5	56 trees	
Percentile	8.9	14.3	25.0	44.6	51.8	67.9	76.8	83.9	91.1	100.0	100 percent	
Average clear stem length (feet)	31.4	28.3	30.3	28.1	26.0	33.8	21.0	26.0	26.8	30.8	—	—

(table 2); and 80—an excellent site (table 3). Essentially these three classes cover the site range in which red oak is an important component of forest stands.

Matching the 10-year diameter growth rates with the percentile provides values for the acceptance of plus trees. For example, if only trees growing in the upper 10 percent of the range are acceptable, then the following rates would qualify: site index 60—over 2.6 inches in 10 years; site index 70—over 2.8 inches; and site index 80—over 3.2 inches.

LENGTH OF CLEAR STEM

Length of clear stem, determined by the point at which the crown begins, is measured from the ground line on the uphill side to this point. As stated previously, this point is permanently established for red oak by the time trees are 40 years old. Distributions of clear-stem lengths have been computed for oak site-index classes 60, 70, and 80 (tables 1, 2, 3).

As with diameter growth rates, matching lengths of clear stem with percentiles provides values for acceptance of plus trees. If only trees with clear stem lengths in the upper third of the range are acceptable, the following lengths would qualify: site index 60—over 31 feet; site index 70—over 32 feet; and site index 80—over 40 feet.

Because the distribution of sample-tree clear lengths is not proportional by site classes,[2] it might be desirable to make an adjustment. For example, set the acceptable length for site index 60 a little lower than 31 feet and the level for site index 70 a little higher than 32 feet. The important point is not the exact level at which to set acceptability, but that these arrays, measured on definite tree classes, offer a means of estimating the relative superiority of one tree over another in terms of clear stem length.

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[2] Part of the reason for this is that the sampling by site classes was skewed: for the site index 60 range the average was 61; for the 70 range it was 69; and for the 80 range it was 80. In other words, the spread between site index classes 60 and 70 was 8 feet and between 70 and 80 it was 11 feet.

Table 2. — Number of trees by diameter growth rates and length of clear stem; northern red oak, site index 70

Clear stem length (feet)	10-year d.b.h. growth (i.b.) in inches																	Total	
	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	4.2	4.4	Frequency	Percentile
13	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	1	0.8
16	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1	1.6
19	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	1	2.4
20	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	1	3.1
21	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	1	3.9
22	—	1	—	1	—	—	2	2	—	—	—	—	—	1	—	—	1	8	10.2
23	—	—	1	1	1	—	1	1	—	—	—	1	—	—	—	—	—	6	15.0
24	—	—	—	2	—	2	—	—	1	—	1	—	—	—	—	—	—	6	19.7
25	—	—	—	—	—	—	—	1	—	1	1	—	—	—	1	—	—	4	22.8
26	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	2	24.4
27	—	—	—	—	1	2	1	1	1	—	1	—	—	—	—	—	—	7	29.9
28	—	—	1	—	1	—	3	1	3	1	—	1	—	—	—	—	—	11	38.6
29	—	—	—	1	—	2	—	—	1	1	1	1	—	—	—	1	—	8	44.9
30	—	—	—	2	—	1	1	—	1	—	—	—	—	—	—	—	—	5	48.8
31	—	—	1	2	1	1	—	1	—	1	—	—	—	—	—	—	—	7	54.3
32	—	—	—	—	2	—	3	3	1	—	—	—	1	—	—	—	—	10	62.2
33	2	—	—	1	1	1	1	1	—	1	—	1	—	—	—	—	—	9	69.3
34	—	—	1	1	2	2	—	1	2	—	—	—	—	—	1	—	—	10	77.2
35	—	—	—	—	—	1	1	—	1	1	1	—	—	—	—	—	—	5	81.1
36	—	—	1	1	2	1	1	—	—	—	—	—	—	—	—	—	—	6	85.8
37	—	—	—	—	—	2	1	—	—	—	—	—	—	—	—	—	—	3	88.2
38	—	—	—	1	1	—	—	1	—	—	—	—	—	—	—	—	—	3	90.6
39	—	—	—	1	—	—	1	—	—	—	1	—	—	—	—	—	—	3	92.9
40	—	—	—	—	1	—	1	—	—	—	1	—	—	—	—	—	—	3	95.3
41	—	—	—	—	—	1	—	—	—	—	—	—	—	1	—	—	—	2	96.8
42	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	1	97.6
43	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	1	98.4
44	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	99.2
46	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1	100.0
Frequency	2	2	5	15	15	16	19	15	13	6	8	4	1	2	2	1	1	127 trees	
Percentile	1.6	3.1	7.1	18.9	30.7	43.3	58.3	70.1	80.3	85.0	91.3	94.5	95.3	96.8	98.4	99.2	100.0	100 percent	
Average clear stem length (feet)	33.0	33.0	30.4	29.1	32.4	31.8	30.3	28.0	31.8	30.2	29.8	28.2	32.0	31.5	29.5	29.0	22.0	—	—

Table 3. — Number of trees by diameter growth rate and length of clear stem; northern red oak, site index 80

Clear stem length (feet)	10-year d.b.h growth (i.b.), in inches																Total	
	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0	Frequency	Percentile
24	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	1	0.9
25	—	—	—	—	—	—	1	1	—	—	—	—	—	—	—	—	2	2.8
26	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	1	3.7
27	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	4.6
28	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	1	5.5
29	—	—	—	—	—	—	—	—	—	1	—	—	—	1	—	—	2	7.3
30	—	—	—	—	—	1	1	—	1	—	—	—	—	—	—	—	3	10.1
31	—	—	—	—	—	1	—	—	—	—	—	1	—	—	—	—	2	11.9
32	—	—	1	1	1	2	3	2	—	2	—	—	—	—	—	—	12	22.9
33	—	—	—	—	2	—	1	—	1	—	—	—	—	—	—	—	4	26.6
34	—	—	—	1	—	—	—	1	—	1	1	—	—	—	—	—	4	30.3
35	—	—	1	—	—	—	—	1	1	—	—	—	—	1	—	—	4	33.9
36	—	—	1	—	—	1	—	2	2	—	—	—	—	—	—	—	6	39.4
37	—	—	—	1	—	—	1	1	1	1	1	1	—	—	—	—	7	45.9
38	—	—	—	1	—	—	1	—	1	—	—	—	1	—	1	—	5	50.5
39	—	—	—	—	—	—	—	1	1	4	—	—	—	—	—	—	6	56.0
40	1	—	—	2	—	—	2	—	—	—	1	—	—	1	1	—	8	63.3
41	1	—	—	2	—	—	—	1	—	—	—	—	—	—	1	—	5	67.9
42	—	—	—	2	1	1	—	2	2	—	—	—	—	—	—	—	8	75.2
43	—	—	—	—	—	2	1	—	—	1	—	—	1	—	—	—	5	79.8
44	—	—	1	—	—	—	1	1	—	—	—	—	—	—	—	—	3	82.6
45	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	1	2	84.4
46	—	—	1	1	—	1	—	1	1	—	1	1	—	—	—	—	7	90.8
47	—	1	—	—	—	—	—	—	—	1	—	—	—	—	—	—	2	92.7
48	—	—	—	—	—	—	1	—	—	—	—	—	1	1	—	—	3	95.4
49	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—	2	97.2
52	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	1	98.2
54	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	1	99.1
60	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1	100.0
Frequency	3	1	7	13	5	11	13	14	11	12	5	3	3	4	3	1	109 trees	
Percentile	2.8	3.7	10.1	22.0	26.6	36.7	48.6	61.5	71.6	82.6	87.2	89.9	92.7	96.3	99.1	100.0	100 percent	
Average clear stem length (feet)	36.0	47.0	38.7	41.7	37.8	37.5	36.5	37.2	37.6	37.9	37.0	38.0	43.0	38.0	39.7	45.0	—	—

OTHER TREE FEATURES OF INTEREST IN A TREE SELECTION PROGRAM

We will not attempt to cover all the tree features that might be considered in a plus-tree selection program, but we will discuss some quality factors pertinent to red oak.

First, we suggest that an acceptance level for sweep or crook in the butt log be set somewhere below 15 percent. Fifteen percent is the maximum allowed for a grade-1 log (*Ostrander and others 1965*).

Second, we suggest that grade factors other than sweep and crook be recognized. Serious consideration should be given to discarding trees with an unusual number of dormant bud clusters, epicormic branches, and/or a profusion of slow-healing branch scars. The following publications should be studied before threshold levels are set for the acceptance of log-quality features: (1) A GUIDE TO HARDWOOD LOG GRADING (*Ostrander and others 1965*), (2) POTENTIAL TREE GRADE OF YOUNG RED OAKS GROWING IN EVEN-AGED STANDS (*Ward 1964*), and (3) PROVISIONAL GRADE SPECIFICATIONS FOR HARDWOOD GROWING-STOCK TREES (*Boyce and Carpenter 1968*).

DISCUSSION

Selection for one feature may be incompatible with selection for other desirable features. This is true of some species in selection for length of clear stem and diameter growth rate.

Trees with long clear stems and short crowns tend to grow slower than trees of the same size that have shorter stems and longer crowns. Holsoe (*1950*), finding this to be true of yellow-poplar (*Liriodendron tulipifera* L.), recommended growing relatively short-boled, long-crowned trees.

But the crown form of red oak is different from that of yellow-poplar. Red oak has a deliquescent form: yellow-poplar has an excurrent form.

To determine the effect of the crown ratio for red oak, correlation coefficients were calculated for the relationship between length of clear bole and d.b.h. growth. The correlation coefficients were negative, but close to zero and nonsignificant. Scatter diagrams (tables 1, 2, and 3) indicate that d.b.h. growth is independent of the length of clear bole.

However, imposing clear-length restrictions onto diameter growth limitations does reduce the number of plus trees that will be chosen. The probability that a tree is a plus tree in both diameter growth and length of clear bole is equal to the product of probabilities of each of the plus classes.

Thus, if we wanted plus trees to be in the upper 10 percent for diameter growth and the upper 30 percent for clear length, we would expect 3 out of 100 trees to qualify.

Table 4 (using data from tables 1, 2, and 3) shows the number and percentage of trees within diameter-growth classes, by clear-stem percentiles. The percentages give estimates of the probabilities of finding plus trees in the given percentiles of both characteristics. In areas of site index 60, for example, we would expect to find about two trees per hundred with a 10-year d.b.h. growth rate over 2.6 inches and a clear bole length over 36 feet.

Restrictions on other factors will further reduce the chances of finding acceptable plus trees. In designing a plus-tree selection program, keep this fact clearly in mind and be careful in determining the primary selection objective. You should set levels of acceptance for less important variables that do not too drastically curtail the chances of finding plus trees, yet the thresholds must be high enough so that trees with poor heritable characteristics are not selected.

In a red oak selection program aimed primarily at developing improved veneer and sawlog trees, growth rate is of primary importance, and upper logs are of minor economic value.

The main interest in clear length should be to select trees with above-average clear bole length for the site. To meet the objective, acceptable values of growth might be set between the 80 and 90 percentiles, and thresholds for length of clear stem might be set between the 50 and 65 percentiles. Thresholds for other features should be treated accordingly.

Success in the use of this method of selecting plus trees depends

Table 4. — Number and percent of red oak trees by clear-stem percentiles within two diameter-growth classes on three sites

Percentile (and clear stem length)	10-year d.b.h. growth (i.b.)			
	Number of trees	*Percent of total*	*Number of trees*	*Percent of total*
	SITE INDEX 60			
	Over 2.6 inches		*Over 2.4 inches*	
Upper 10 (over 36 feet)	1	1.8	1	1.8
Upper 20 (over 33 feet)	1	1.8	1	1.8
Upper 35 (over 31 feet)	3	5.4	3	5.4
Upper 50 (over 28 feet)	4	7.1	5	8.9
Upper 100 (all lengths)	5	8.9	9	16.1
	SITE INDEX 70			
	Over 2.8 inches		*Over 2.6 inches*	
Upper 10 (over 38 feet)	1	0.7	3	2.4
Upper 20 (over 35 feet)	1	.7	3	2.4
Upper 35 (over 32 feet)	3	2.4	6	4.7
Upper 50 (over 30 feet)	4	3.1	7	5.5
Upper 100 (all lengths)	11	8.7	19	15.0
	SITE INDEX 80			
	Over 3.2 inches		*Over 2.8 inches*	
Upper 10 (over 46 feet)	2	1.8	2	1.8
Upper 20 (over 43 feet)	3	2.8	5	4.6
Upper 35 (over 40 feet)	5	4.6	7	6.4
Upper 50 (over 38 feet)	7	6.4	10	9.2
Upper 100 (all lengths)	11	10.1	19	17.4

upon reasonably accurate recognition of site quality. Unfortunately, such recognition is not uniformly feasible. For oak, in many locations, site studies have been used to develop methods of determining site index that depend on measurable soil and topographic features. While this same situation exists for some other important species and locations, there are many situations for which no soil-site data are available. And in some instances, where such data are available, the measurement of the prediction variables is so time-consuming and difficult that the advantages of using the procedure described in this paper are nullified.

In areas where the species involved is a frequent component of the forest stands, enough suitable trees are usually available near the candidate tree to determine an average site index from height-over-age relationships. Also, where site quality is relatively uniform over wide areas, such as in flat regions with similar soil conditions, site-index determinations made on a group of suitable trees may be extrapolated over long distances.

The following cases, and combinations of them, represent the most difficult situations for determination of site index: (1) areas where site changes are frequent and large; (2) areas and species for which soil-site information is not available or is difficult to apply; (3) stands in which the species of interest are widely scattered; and (4) where the personnel assigned to this work are not experienced in the area, with the species, nor in site determination.

Plus-tree selection is a first step in one type of tree-improvement program. The trees selected are phenotypes. The real test of heritable traits comes when the progeny are compared. For many species, the frequency distribution of the characteristics of interest may be available or easily collected. If so, and if problems of site quality determination can be resolved, the data should be used in selecting plus trees.

■

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THE FOREST SERVICE of the U. S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

University of Vermont
Agricultural Experiment Station Journal Article 229

Some Effects of PARAFORMALDEHYDE on Wood Surrounding Tapholes in SUGAR MAPLE Trees

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by Alex L. Shigo
and Frederick M. Laing

U.S.D.A. FOREST SERVICE RESEARCH PAPER NE-161
1970

NORTHEASTERN FOREST EXPERIMENT STATION, UPPER DARBY, PA.
FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
RICHARD D. LANE, DIRECTOR

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BUT WHAT DOES THE PILL DO TO THE TREE?

PILLS OF PARAFORMALDEHYDE (trioxymethylene) are commonly used in tapholes in sugar maple trees (*Acer saccharum* Marsh.) to increase the yield of sap collected for making syrup and sugar (*2, 4, 5, 8*). The explanation offered for this increase in sap yield is that microorganisms in the tapholes (*7*) cause premature decline and stoppage of the sap flow (*1, 6*), but that paraformaldehyde increases sap yield by inhibiting their growth (*2*).

But what happens to the tree? To determine the effects of paraformaldehyde on the tissues surrounding tapholes, and on the microorganisms in those tissues, sugar maple trees were dissected and studied. This paper is a report on that study.

MATERIALS & METHODS

On 13 March 1969, five sugar maple trees on the Proctor Maple Research Farm, near Underhill Center, Vermont, and five trees on the Mitchell Farm, near Jericho, Vermont, were tapped. The diameters of the trees at 1.4 m. above ground ranged from 25 to 45 cm. In each tree 10 tapholes were drilled: 5 spaced equally around the tree at 60 cm. above the ground, and 5 at 120 cm. The tapholes, 1 cm. in diameter, penetrated the tree 6 cm. Paraformaldehyde pills—250 mg. each—were inserted into 5 of the 10 tapholes, at random, in each tree. The tapholes containing the pills were marked. A plastic spout of the type used for collecting sap was inserted into each taphole, although no sap was collected. The spouts were removed on 24 April.

The five trees on the Proctor Farm were felled on 5 May, as low on the stump as possible. After felling, a second cut was made 60 cm. above the upper tapholes. The ends of these approximately 180-cm. bolts were wrapped immediately with plastic sheets and heavy paper. The bolts were delivered to the Northeastern Forest Experiment Station's laboratory in Durham, New Hampshire, the morning of 6 May. The five trees on the Mitchell Farm were cut on 12 May, and the bolts were delivered to

Durham on 13 May. They received the same treatment as the bolts from the Proctor Farm.

Ten billets, approximately 30 x 8 x 8 cm., with the taphole in the center (figs. 1 and 2), were dissected from each bolt. The bark was removed from each billet. The billets were taken into a clean room and split longitudinally through the taphole with a sterile ax. Care was taken so the ax did not touch the tissues surrounding the taphole, from which wood chips were taken for isolating microorganisms.

Isolations for microorganisms were made by extracting with a

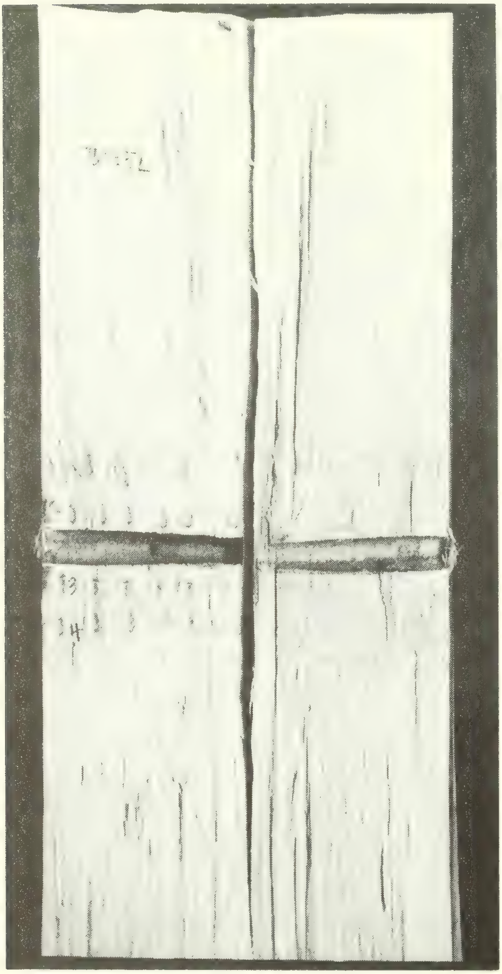
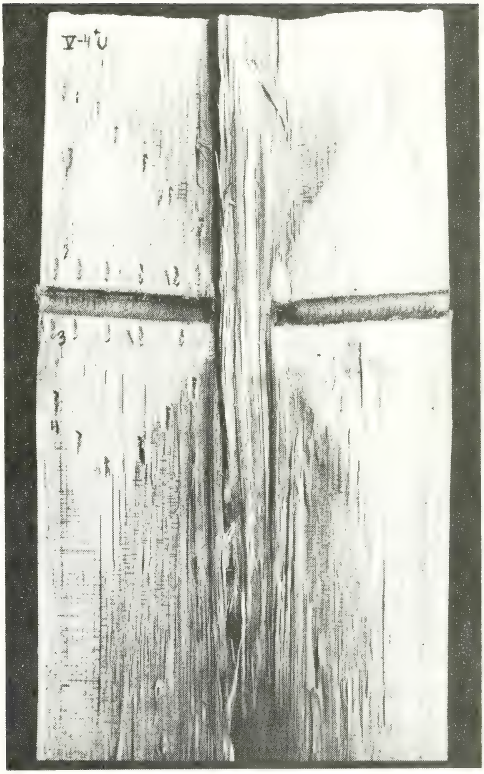


Figure 1. — Dissection of a taphole that did not receive a paraformaldehyde pill; after 60 days. The discolored area above and below the taphole was very faint and, after the wood dried, it was difficult to see the discolored area. The small holes above and below the tapholes mark the position of the chips of wood taken for isolating microorganisms.

Figure 2. — Dissection of a taphole that did receive a paraformaldehyde pill; after 60 days. The discolored area appeared as a bleached zone after the wood dried. The tissues in this zone were killed. The small holes in the wood mark the position of the chips of wood taken for isolating microorganisms. The distal margins of the bleached zones fluoresced under ultraviolet light.



sterile gouge chips of wood approximately 1 x .3 cm. in a row 1 cm. above and below the taphole, and near the margin of the discolored area (figs. 1 and 2). At least 24 chips were taken from each billet. The chips were placed in a growth medium consisting of 10 g. malt extract, 2 g. yeast extract, and 20 g. agar per liter of distilled water.

The cultures were incubated at 25°C. and were examined several times over a period of a month. The bottoms of the chips were also examined, for bacteria.

After the chips had been extracted, the freshly cut halves of the billets were placed under an ultraviolet light. The margins of the discolored areas fluoresced. The vertical limits of the discolored areas were measured to the boundaries of the fluorescing zones. Streaks of discolored tissues often extended far beyond these boundaries.

In addition, seven trees on the Roger Grimes Sugar Orchard in North Hyde Park, Vermont, were dissected and examined. These trees had tapholes that had received the 250-mg. paraformaldehyde pills 2 and 3 years before dissection (fig. 3). Isolations for microorganisms were made in the same manner as described above. Observations were made on the healing of tapholes in this orchard and in a neighboring one where the pills were also used.

Histological studies were conducted to compare the tissues surrounding tapholes that had received the pills with those that

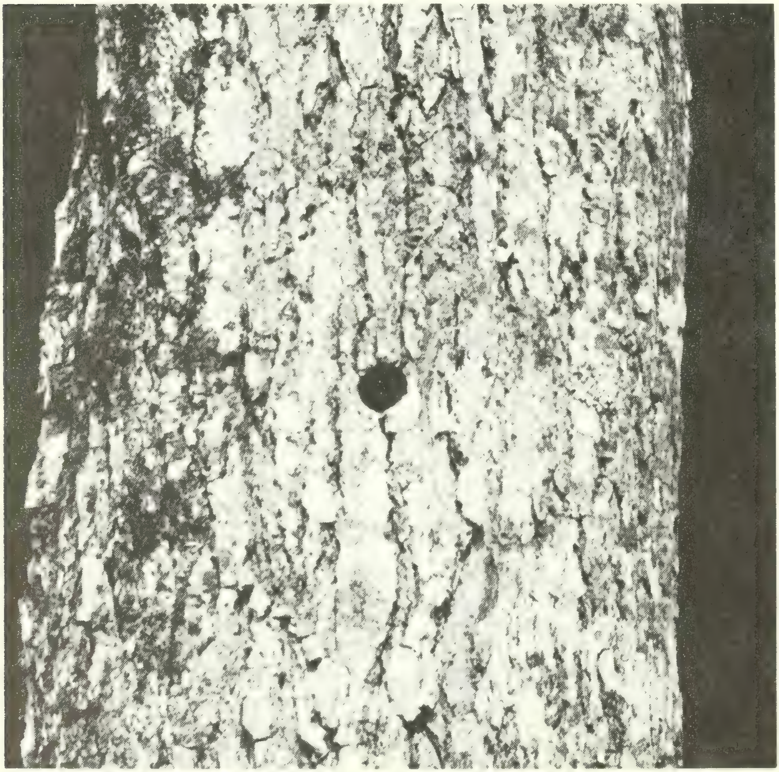


Figure 3. — An unhealed taphole in a sugar maple tree 2 years after a 250-mg. paraformaldehyde pill was inserted to increase yield of sap. The bark must be pulled away from the hole, and the tree must be dissected to assess properly the injury caused by paraformaldehyde.

had not. Other trees on the Proctor Farm were used in these studies.

RESULTS

Discolored Wood Associated with Tapholes

Areas of discolored wood with margins that fluoresced under ultraviolet light (fig. 2) were associated with every taphole that had contained a paraformaldehyde pill (table 1). The tapholes that had not contained pills had areas of only slightly discolored

Table 1. — Lengths of discolored lesions associated with 100 tapholes in 10 trees; 5 tapholes treated and 5 not treated with paraformaldehyde per tree on two farms

Tree	250 mg. paraformaldehyde added per taphole					No paraformaldehyde added				
	Lengths of lesions associated with 5 tapholes per tree: cm[1]					Lengths of lesions associated with 5 tapholes per tree: cm				
PROCTOR FARM: 53 DAYS AFTER TAPPING										
1	15,	12,	12,	12,	11	5,	4,	4,	4,	4
2	20,	20,	15,	14,	14	4,	4,	4,	4,	4
3	15,	10,	10,	10,	9	4,	4,	4,	3,	3
4	14,	12,	12,	10,	5	12,	8,	7,	5,	5
5	14,	12,	10,	8,	8	5,	5,	5,	4,	3
	Average 12.16 cm.					Average 4.72 cm.				
MITCHELL FARM: 60 DAYS AFTER TAPPING										
6	25,	24,	23,	22,	14	5,	4,	4,	4,	4
7	26,	20,	15,	15,	15	6,	5,	4,	4,	3
8	30,	22,	18,	17,	15	5,	5,	5,	4,	4
9	30,	25,	16,	15,	15	6,	3,	3,	3,	3
10	20,	20,	18,	18,	17	6,	6,	5,	4,	3
	Average 19.8 cm.					Average 4.96 cm.				

---

[1] Boundary of lesion fluoresced under ultraviolet light. Measurements were made to these boundaries.

wood (fig. 1), a few cm. above and below the taphole (table 1). In these, the fluorescence under ultraviolet light was very weak at the margins. The most intense fluorescence was in the tissues immediately behind the taphole. The slightly discolored wood surrounding the tapholes that did not receive the pill faded in a few hours, and there was no difference in color between these tissues and healthy tissues. The discolored areas of wood sur-

Table 2. — Number of wood chips that yielded microorganisms from above and below 100 tapholes in 10 trees; 5 tapholes treated and 5 not treated with paraformaldehyde per tree on two farms

	250 mg. paraformaldehyde added per taphole			No paraformaldehyde added		
Tree	Number of wood chips from 5 tapholes	Yielded bacteria	Yielded fungi	Number of wood chips from 5 tapholes	Yielded bacteria	Yielded fungi
PROCTOR FARM: 53 DAYS AFTER TAPPING						
1	90	84	10	60	60	1
2	120	109	20	120	119	8
3	96	85	13	108	108	2
4	138	131	39	96	96	42
5	126	119	22	120	120	13
Total	570	528	104	514	503	66
Percent	—	93	18	—	98	13
MITCHELL FARM: 60 DAYS AFTER TAPPING						
6	120	108	25	96	96	13
7	120	96	41	108	108	28
8	120	107	35	120	117	22
9	120	100	69	120	115	41
10	120	104	42	96	93	32
Total	600	515	212	540	529	136
Percent	—	86	35	—	98	25

rounding the tapholes that had contained the pills appeared bleached after the wood dried.

The trees from the Mitchell Farm contained the pill a week longer than the trees from the Proctor Farm. The average length of the discolored areas in these trees was greater (19.8 cm.) than the average length of those from the Proctor Farm (12.16 cm.). Yet there was very little difference between the average lengths of the discolored areas in the trees on the two farms that did not receive the pill (table 1).

Microorganisms Associated with Tapholes

There was very little difference in the frequency of isolation of microorganisms from tissues surrounding tapholes, whether or not the tapholes had contained the paraformaldehyde pills (table 2).

By comparison with identified cultures from sugar maple, the

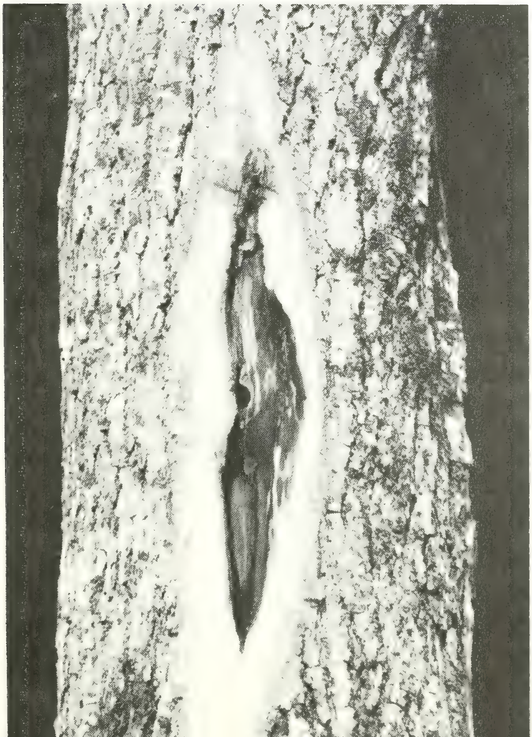


Figure 4. — The removal of the bark surrounding the taphole of the tree shown in figure 3 reveals the wood killed by paraformaldehyde. Tissues to the side of the hole were killed also. Wood-inhabiting microorganisms rapidly invade these killed tissues.

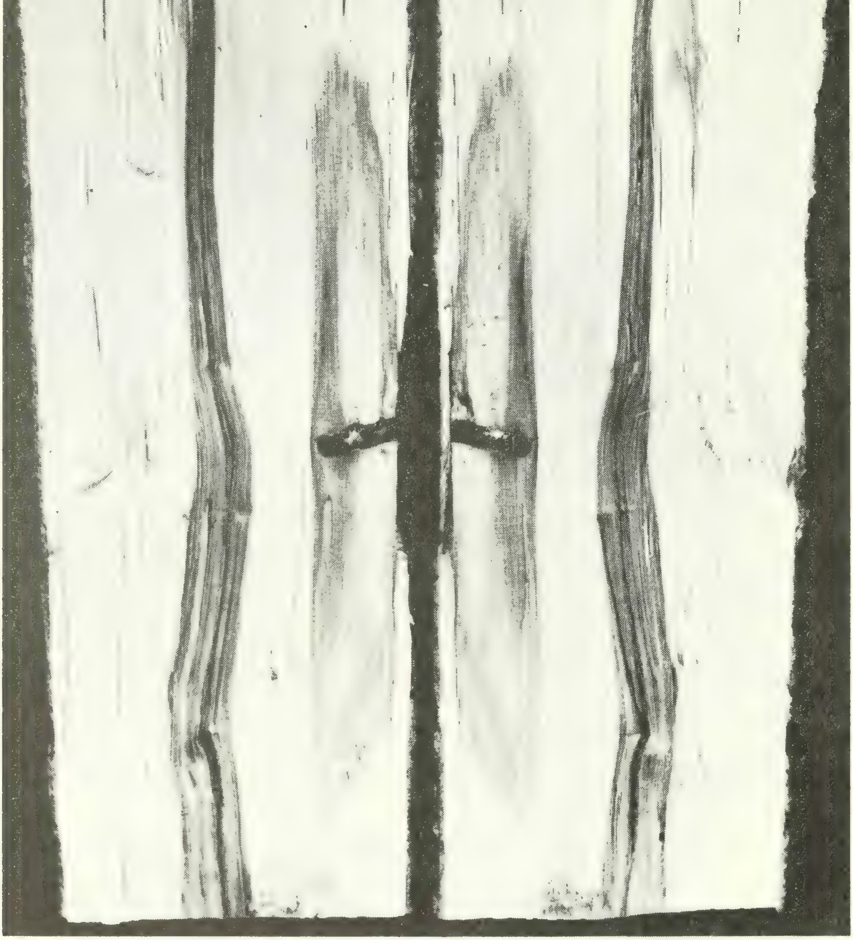


Figure 5. — Dissection of a taphole 2 years after a 250-mg. paraformaldehyde pill was inserted. The bleached wood is decayed. The tissues were killed several inches above and below the taphole.

principal bacteria were identified tentatively as species of *Pseudomones* and *Bacillus.*

The fungi isolated were of the genera *Phialophora, Ascocoryne, Margarinomyces, Phoma, Alternaria, Penicillium, Fusarium, Gliocladium, Cephalosporium, Cladosporium,* and *Candida* (a filamentous yeast).

There was no noticeable difference between the species of microorganisms isolated from the treated and untreated tapholes.

Observations on Other Trees

Decayed wood was associated with tapholes that had received the pill 2 and 3 years ago in many of the trees examined in the Roger Grimes Orchard (figs. 4 and 5). The injury was not obvious until the bark surrounding the taphole was removed (fig. 4). On many trees there were dead areas lateral to the taphole (fig. 4). On trees in a neighboring farm, some injury was found, but not as extensive as that in the Grimes Orchard.

Histological Studies

Vessels in the wood surrounding tapholes that had not received the pill were plugged with an amber-colored material. This material is similar to that reported by Good *et al.* (3) as normally found in vessels in tissues surrounding wounds. In wood tissues surrounding tapholes that had received the pill, no such plugs were found in the vessels. These tissues were bleached. However, vessel plugs were found in the distal margins of the bleached tissues.

CONCLUSIONS

All tapholes that had received the 250-mg. paraformaldehyde pills had associated with them discolored areas that appeared bleached after the wood dried. Tapholes that did not receive the pill did not have such discolored areas.

Vessel plugs were absent in the bleached tissues. These results indicate that paraformaldehyde killed tissues in the tree. Vessel-plug formation is the result of a dynamic process. When tissues are killed quickly, they cannot respond; and no plugs form.

Decay was advanced above and below tapholes in trees that had received the pill 2 and 3 years ago, probably because the tissues were killed quickly around the taphole. The microorganisms that invade wood and incite discoloration and decay could then easily invade the dead tissues. In this way, the pill greatly enhances the establishment of wood-destroying microorganisms. And, even more damaging, killing of tissues around the taphole may result from the use of paraformaldehyde.

Paraformaldehyde indeed will kill and inhibit the growth of a wide variety of microorganisms (2). There is little doubt that this chemical does inhibit the growth of microorganisms in the taphole (8). But paraformaldehyde does little to inhibit the growth of microorganisms once they have invaded the wood. Paraformaldehyde may even enhance the growth of certain wood-inhabiting microorganisms by inhibiting the growth of competing microorganisms on the inside surface of the taphole. Regardless, there were just as many microorganisms in the wood surrounding the tapholes that contained the pill as in the wood surrounding tapholes that did not contain it.

A taphole is a wound. Trees have repair processes, as do all organisms, to heal wounds. Many factors affect these processes: the vigor of the tree, the severity of the wound, and microorganisms—to mention a few. If wound-healing did not occur, there would be no trees to tap. It appears that paraformaldehyde blocks the repair system of a tree. Microorganisms that destroy wood then invade.

Paraformaldehyde increases yield of sap not only by inhibiting the growth of microorganisms in the taphole, but by killing tissues that surround the taphole. The vessels in these dead tissues do not contain plugs. In a sense, paraformaldehyde makes a larger hole in the tree.

■

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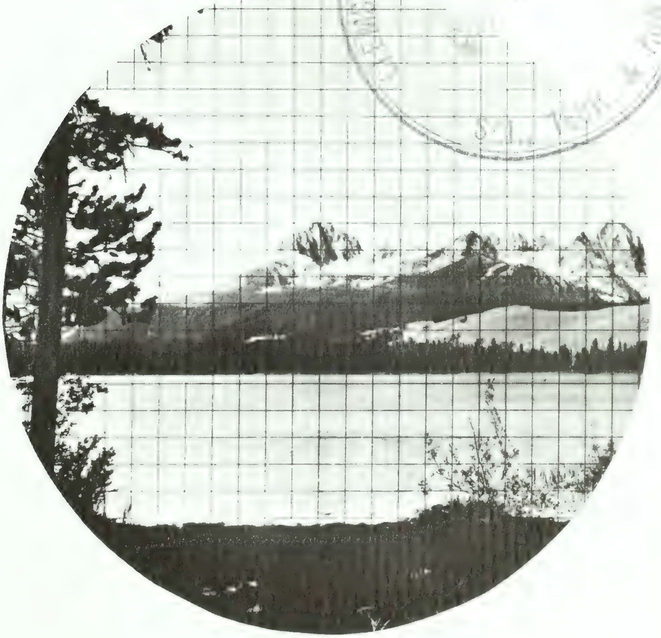
It Seems Possible to Quantify Scenic Beauty in Photographs



by Elwood L. Shafer, Jr.
and James Mietz

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NORTHEASTERN FOREST EXPERIMENT STATION, UPPER DARBY, PA.
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JAMES MIETZ, at the time of this study, was a senior forestry student at Utah State University. He is serving with the U.S. Army in South Vietnam.

TO PARAPHRASE KIPLING: East is West, and West is East—as far as a recent experiment in landscape preference is concerned. Our study indicated that recreationists in Utah and New York prefer the same kind of forest landscapes—when the landscapes are depicted by 8- by 10-inch black-and-white photographs.

A landscape-preference model that was developed and tested on recreationists in New York *(Shafer and others 1969)* predicted the overall landscape preference pattern of outdoor recreationists near Salt Lake City, Utah. Results of our experiment suggest that the model can be used by regional planners throughout the United States to help evaluate and compare quantitatively the aesthetic quality of different landscapes.

When it was developed, the model explained 66 percent of the variation in landscape preference scores of 250 Adirondack campers. Also, in independent field tests, the model predicted the overall landscape preferences of 300 other campers throughout New York State *(Shafer and others 1969)*. Thus, we knew the model worked in the Northeast. The next step was to test how well the model predicted preferences of western recreationists; that was the objective of this study. The study was conducted in cooperation with Utah State University.

THE MODEL

First, it is necessary to briefly describe how the model was developed and how it works.

Initially, we defined eight zones within a landscape photograph:

Zone A. *Sky and clouds:* All sky and cloud areas.

Zone B. *Immediate trees and shrubs:* Those parts of a photo where individual leaf and bark characteristics are visible if in full light.

Zone C. *Intermediate trees and shrubs:* Areas on a photo where outlines of individual trees and shrubs can be recognized but not in the fine detail found in zone B.

Zone D. *Distant trees and shrubs:* Areas where shapes of individual trees and shrubs cannot be distinguished.

Zone E. *Immediate other features:* Areas that contain rocks, grass, snow, or soil and where the texture, blades of grass, or detailed characteristics of the individual rocks and boulders can be distinguished if in full light.

Zone F. *Intermediate other features:* Places where the outlines of large rocks, large crevices, or prominent features of soil, grass, or snow are visible but not in the detail found in zone E.

Zone G. *Distant other features:* Areas where snow, rocks, grass, or soil occur, but no details of these features are visible.

Zone J. *Water:* All water areas, including streams, lakes, waterfalls, and rocks visible within the boundaries of those water areas.

For any 8- by 10-inch black-and-white photograph, the landscape preference model used measurements in six of the eight zones to predict a landscape's preference score (Y).

$$Y = 184.8 - .5436\ X_1 - .09298\ X_2 + .002069\ (X_1 . X_3) + .0005538\ (X_1 . X_4) - .002596\ (X_3 . X_5) + .001634\ (X_2 . X_6) - .008441\ (X_4 . X_6) - .0004131\ (X_4 . X_5) + .0006666\ X_1^2 + .0001327\ X_5^2$$

where:

X_1 = perimeter of the immediate tree-and-shrub zone.
X_2 = perimeter of intermediate other-features zone.
X_3 = perimeter of distant tree-and-shrub zone.
X_4 = area of intermediate tree-and-shrub zone.
X_5 = area of water zone.
X_6 = area of distant other-features zone.

The lower the Y value, the more preferred the landscape.

Values for the independent variables were obtained by placing a ¼-inch plastic grid over a photograph (fig. 1) and making landscape-zone area or perimeter measurements as follows:

- The eight landscape zones are outlined on a photograph by using the edges of the squares as boundary lines. All six zones will not necessarily occur on any one photograph.
- The perimeter measurement for variable X_1, X_2, or X_3 is the total number of ¼-inch edges of each square along the boundary of that particular zone. If a zone occurs at different locations on the photo, add that zone's perimeter measurements for all locations.
- The area measurement for variables X_4, X_5, or X_6 is the total number of ¼-inch squares within that specific zone. Again, if a given zone occurs at different locations, add that zone's area measurements for all locations.

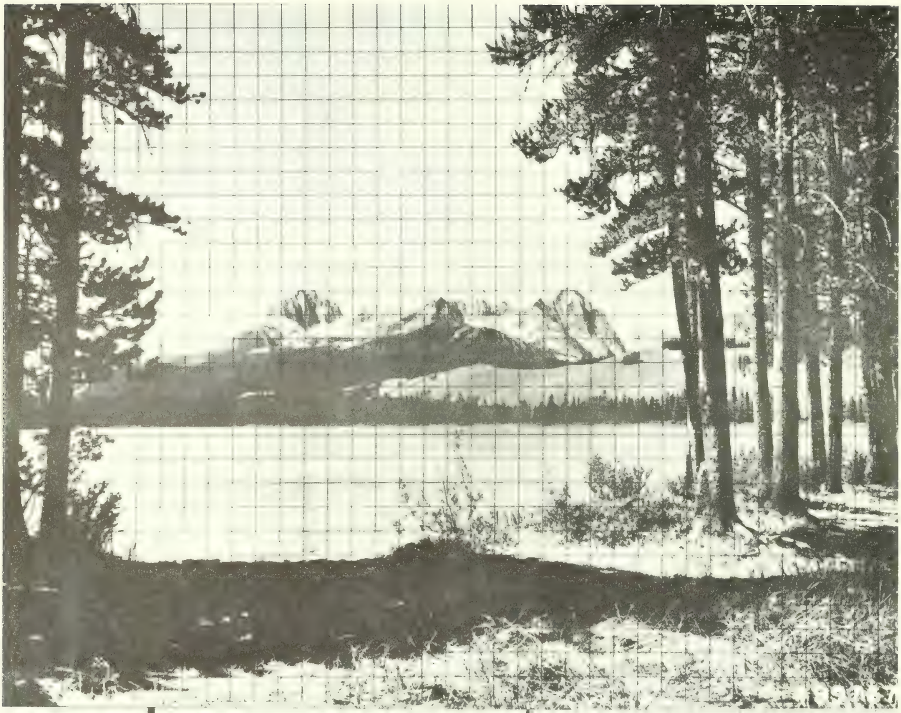
STUDY PROCEDURE

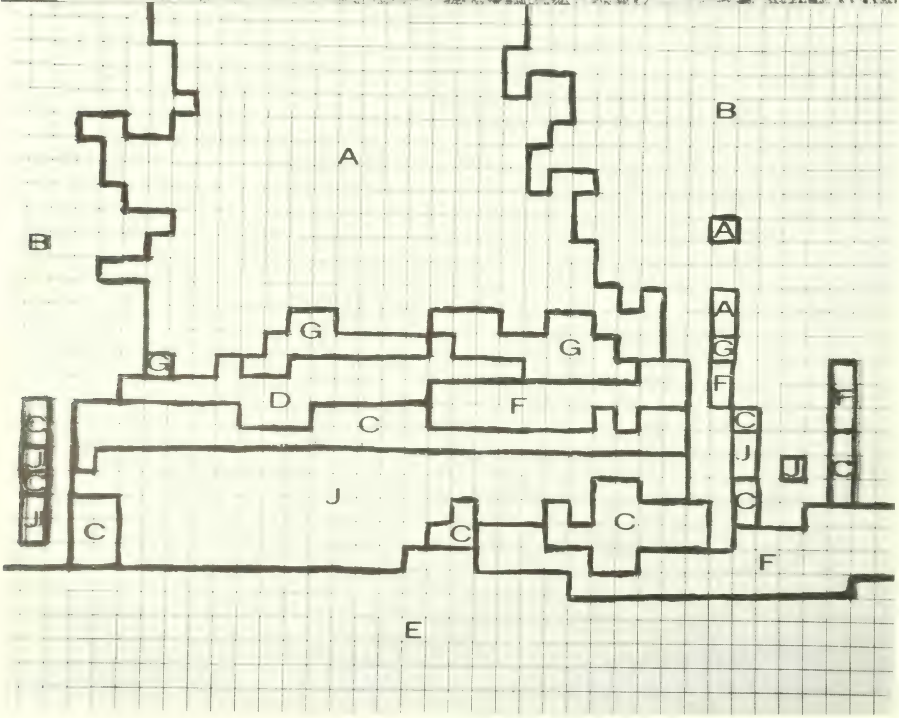
Initially, fourteen 8- by 10-inch photos were selected randomly from the original 100 photos used to develop the model. The 14 photos were sorted randomly into two sets—A and B—with seven photos in each set (figs. 2 and 3).

In August 1967, we randomly selected 50 day-users throughout the Big Cottonwood and Mill Creek Canyon recreation areas on the Wasatch National Forest—a half hour's drive from Salt Lake City, Utah. Each of the 50 respondents was asked to rank the seven landscapes in each set. The photo ranked first was the most preferred, and so on until the photos were ranked 1 through 7 per set. We restricted the interviews to people who lived in the Salt Lake City area. All respondents were 12 years of age or older. There were no non-respondents.

Thus, each photo received 50 rank values that could range from 1 to 7; the sum of these 50 values was a photo's overall observed preference score (Y'). Theoretically, a Y' value could range from 50 to 350. Observed scores for photos in set A ranged from 128 to 265; in set B, they ranged from 138 to 278.

Next, on each photo we measured the six perimeter or area variables required for the landscape preference model and computed the photo's predicted preference score (Y). Predicted





B
A
B
A
A
G
G
G
G
F
F
D
F
C
C
J
C
C
J
C
J
J
C
C
J
C
C
F
E

Figure 1.—A ¼-inch plastic grid is laid over a photo (top), and the edges of the squares are used to outline the various landscape zones (bottom).

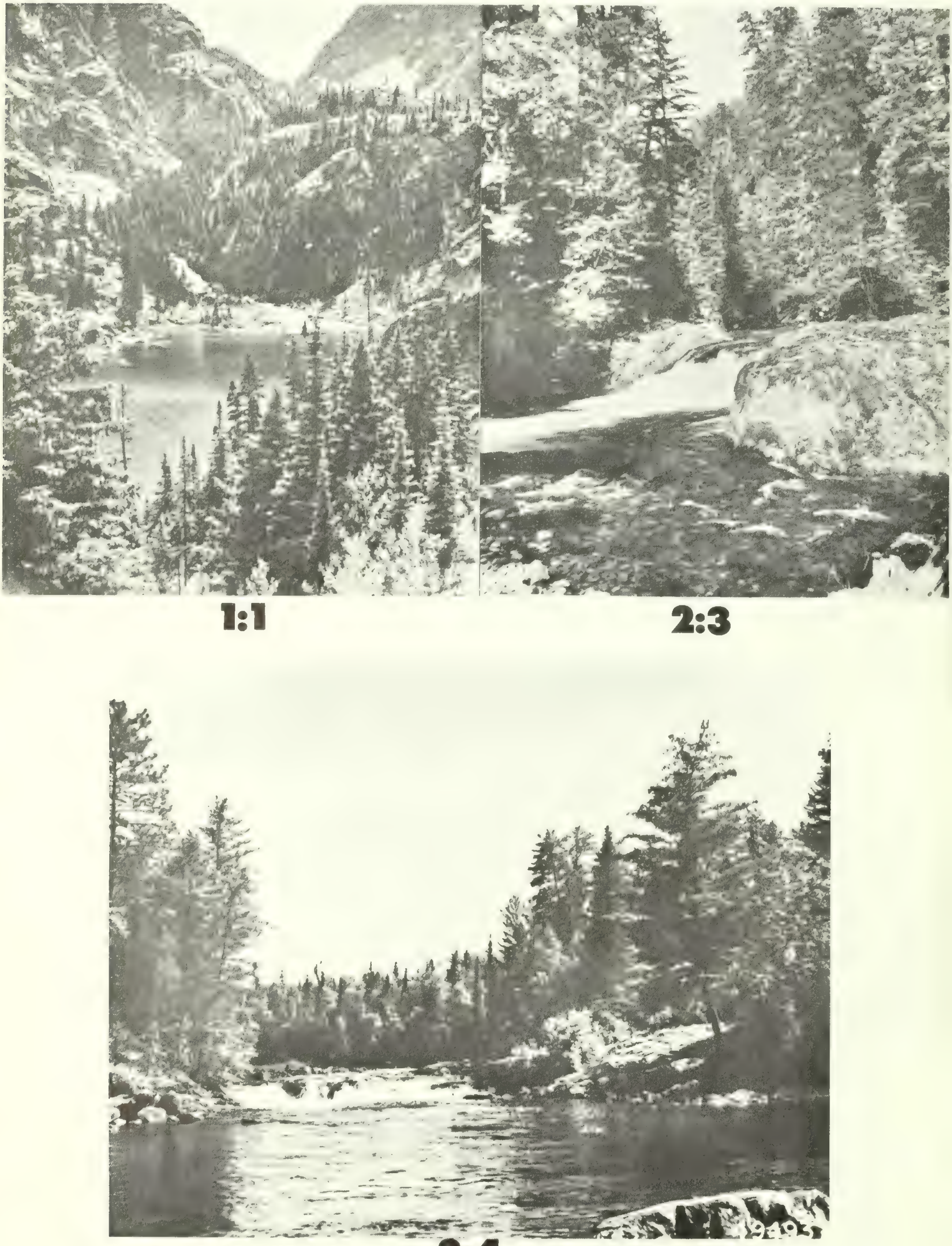
Measurement values for this example are:

Landscape Zone	*Measurement*	*Model variable*	*Value*
A.	Not required	—	—
B.	Perimeter	X_1	226
C.	Area	X_4	77
D.	Perimeter	X_3	44
E.	Not required	—	—
F.	Perimeter	X_2	92
G.	Area	X_6	30
J.	Area	X_5	98

Solving for landscape's preference score:

$$\begin{aligned} Y = {} & 184.8 - .5436\ (226) - .09298\ (92) \\ & + .002069\ (226 \cdot 44) + .0005538\ (226 \cdot 77) \\ & - .002596\ (44 \cdot 98) + .001634\ (92 \cdot 30) \\ & - .008441\ (77 \cdot 30) - .0004131\ (77 \cdot 98) \\ & + .0006666\ (226)^2 + .0001327\ (98)^2 \\ Y = {} & 89 \end{aligned}$$

Figure 2.—Landscape photos used in set A. The two numbers under each photo are its predicted and observed rankings, respectively. The coefficient of concordance = 0.851, and the F value = 5.71, which is significant at the 95-percent level.



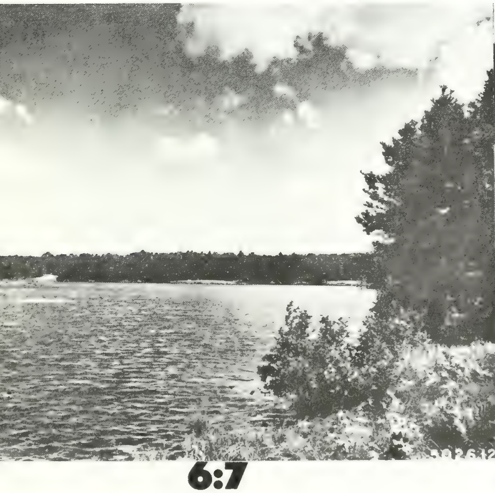
1:1

2:3

3:4

4:5

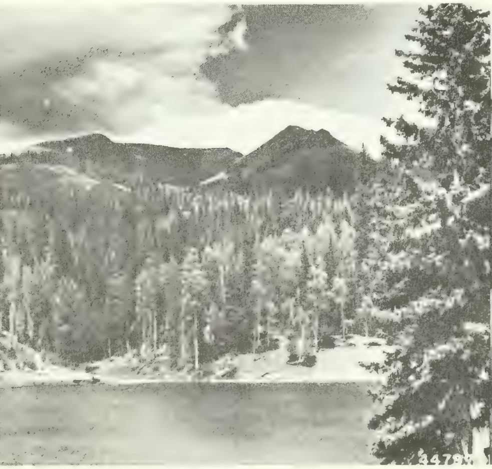
5:2



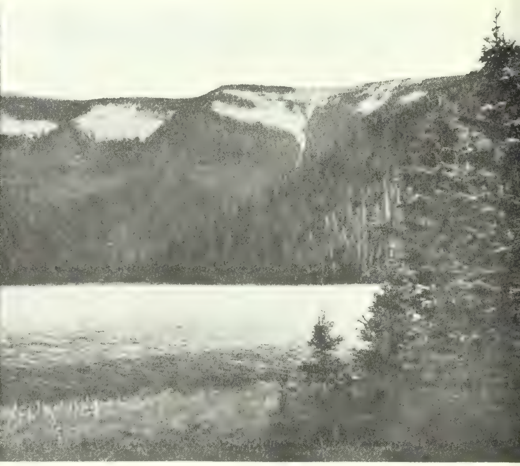
6:7

7:6

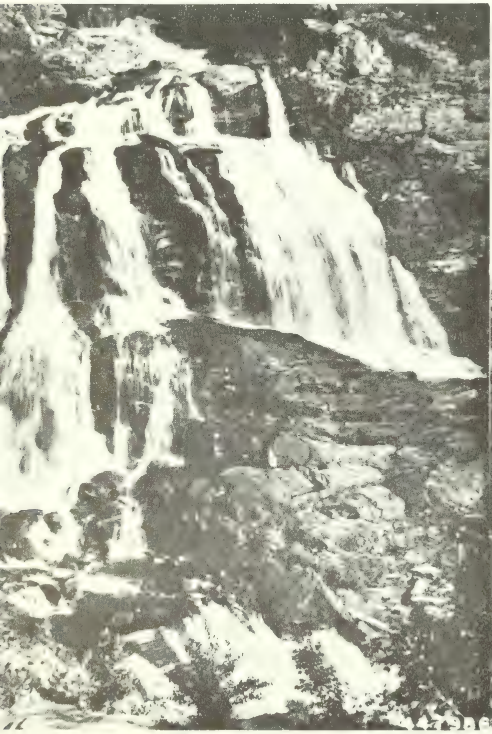
Figure 3.—Landscape photos used in set B. The two numbers under each photo are its predicted and observed ranking, respectively. The coefficient of concordance = 0.921, and the F value = 11.66, which is significant at the 95-percent level.



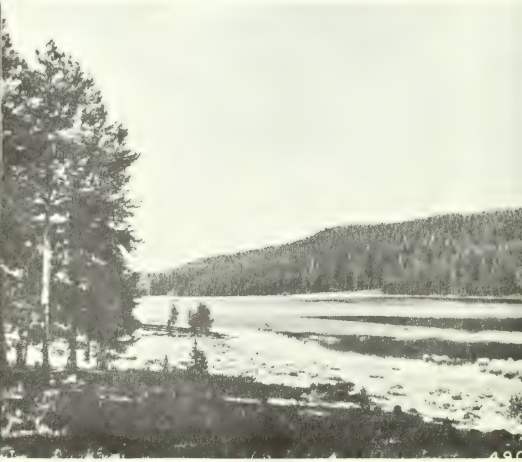
1:3



2:1



3:2



4:4

5:5

6:6

7:7

scores in set A ranged from 71 to 174; set B scores ranged from 99 to 212.

Finally, the observed and predicted preference scores were ranked separately from 1 to 7. The coefficient of concordance *(Walker and Lev 1953)* was used to test how well the observed and predicted ranks agreed. The coefficient was significant for both sets (fig. 2 and 3); this means that the predicted and observed ranks showed agreement far beyond what might be produced by sampling variance.

To understand why we compared rank values rather than numerical scores, consider the following possibility. Assume that a test with seven pictures contains one average — and six below-average-quality landscapes. The average picture will receive a much better score than it would if it were compared with six above-average quality landscapes. Thus, when only seven pictures are used in a test, biased scores could be obtained. To compare observed and predicted scores we would have had to conduct our survey with 100 different photographs as we did when we developed the model. We felt that a comparison between predicted and observed ranks was sufficient to test whether or not the model predicts landscape preferences of western recreationists.

DISCUSSION OF RESULTS

The landscape preference model worked fairly well in the West. Although the model predicts preferences for photos of landscapes—not for the landscapes themselves—the procedure seems realistic and practical. Advantages and disadvantages of using photographs in experiments of this kind are discussed elsewhere *(Shafer and Rutherford 1969)*.

In set A, the observed and predicted ranks never agreed exactly but usually differed by only one rank value (fig. 2). The largest difference between a predicted and observed rank occurred in set A: a watefall was predicted to be ranked fifth but actually ranked second (photo labeled 5:2 in fig. 2). This same photo shows a smaller area of the landscape than any of the other six in the set. Therefore, future surveys that use the model to evaluate landscapes might stratify photos first into macro and micro environments. However, stratification may not always be possible; it depends on the number and variety of landscapes to be evaluated.

All landscapes in set A have some water, but only four landscapes in set B contain water (figs. 2 and 3). Closer agreement between predicted and observed ranks in set B suggests that the model may more accurately predict preferences for landscapes that do not contain water. Perhaps the model could be improved if it included additional variables that describe water environments in more detail.

Such details might include the area and perimeter of dark and light shapes within the total water area and the height of a waterfall in relation to other features in the landscape. In addition, it may be helpful in future research to stratify water areas into lakes, streams, waterfalls, and rivers.

On the basis of observed preference scores in set A, our respondents preferred vaious types of water environments in this order:

Picture	*Observed rank*
Waterfall, stream, and lake combined	1
Mutliple waterfalls	2
Single waterfall and stream (rocky shoreline)	3 and 4
Stream (rocky shoreline)	5
Lake	6
Stream (swampy shoreline)	7

In set B, the observed and predicted ranks were the same for four pictures (fig. 3). However, three of the four photos that included water were ranked differently than predicted. Furthermore, one of these three water scenes was a close-up of a waterfall, while all other photos in set B included a much greater area of landscape.

By knowing that quantitative features in the photo of a landscape affect its aesthetic appeal, resource managers and planners can begin to have a factual basis, in addition to an intuitive one, for decisions about wildland aesthetics.

Results of our study provide several clues that may sharpen the model's predictive capabilities. The main point is that it seems possible to quantify certain aspects of the forest landscape, and furthermore, that our methodology presents a reliable approach. However, additional research is needed to test how well preferences for photos of landscapes compare with preferences for those same landscapes when viewed on the ground.

Granted, our procedure for quantifying aesthetics does not provide an economic value for aesthetic quality; this may never be possible. At the most, the model provides a quantitative index of how much one landscape is generally preferred over another, and therefore, may be used to assign weighted preference value to different natural landscapes.

Future research is needed to determine the relationship, if any, between preference value and the real-estate value of a given landscape. Additional research, using our methodology, is also necessary to predict preference for different elements within an environment—shapes, sizes, and colors of individual trees, for example.

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by E. Paul Craft

Construction-Grade PLYWOOD from Grade 3 APPALACHIAN OAK

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FOREST SERVICE, U. S. DEPARTMENT OF AGRICULTURE
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Construction-Grade PLYWOOD from Grade 3 APPALACHIAN OAK

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PLYWOOD FROM LOW-GRADE OAKS

IN AN EFFORT to find a use for a large volume of the low-grade oak logs of Appalachia, we processed a sample of these logs in a typical southern-pine sheathing plant and determined the feasibility of converting them into construction-grade plywood.

These low-grade logs are available to new industry in large volumes, without disturbing the supply of logs to existing industry. The forests of Appalachia are growing hardwood sawtimber more than twice as fast as it is being used. A major cause for the underutilization of Appalachian hardwoods is the predominance of low-grade logs: about 50 percent of the commercial forest inventory consists of timber that will yield factory grade 3 logs,[1] yet only 30 percent of the logs used by sawmills are grade 3.

Commercial oak species represent 40 percent of the hardwood timber volume in the Appalachians, and they occur in sufficient concentration to support a number of medium-size plywood mills. One-half of the surplus growth of grade 3 oak in West Virginia alone is sufficient to support three plants, each capable of consuming 10 million board feet of timber annually. Therefore, only the oaks were considered in this study, and West Virginia was assumed to be representative of the Appalachian hardwood area (see appendix 1).

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[1] Grade 3 logs referred to in this report are those that meet the requirements for USDA Forest Service Factory grade 3 logs as described in A GUIDE TO HARDWOOD LOG GRADING, USDA Forest Service, Northeastern Forest Experiment Station, Upper Darby, Pennsylvania, 1965.

STUDY PROCEDURE

The sample logs for the pilot test were purchased from a log yard located in Taylor County, West Virginia. Grade 3 oak logs were separated from woods-run logs as they arrived at the log yard. No distinction was made within the grade or among the oak species, except that logs with heart defects that would interfere with chucking in a lathe were rejected. The sample contained 105 logs, of which 77 were chestnut oak, 12 were white oak, and 15 were red oak. The average diameter was 11.7 inches.

The sample logs were processed at the Chesapeake Bay Plywood Company's automated pine-sheathing plant (a subsidiary of U.S. Plywood Corporation) at Pocomoke City, Maryland. No changes were made in the production procedure, machinery, or machinery adjustments normally used for pine, except as noted in the following manufacturing procedure.

MANUFACTURING PROCEDURE

Log-handling system.—The sample logs were loaded by fork truck from the yard onto the receiving deck of a Beloit[2] automatic log-handling system. The logs were moved by chain conveyors to a 35-inch Cambio ring-type debarker and debarked at 90 feet per minute. Logs were then moved by chain conveyors to a 5-foot diameter swing-type cutoff saw and were equalized to 8½-foot lengths. Finally, they were conveyed to storage bins.

Log-conditioning vats.—Logs were moved from storage bins by fork truck to an end-loaded surface-type hot water spray conditioning room and treated with 190°F. water for 24 hours.

Lathe charger.—Logs were moved from the conditioning room by fork truck to the plant receiving deck and were moved by chain conveyor to a Coe automatic centering and prespotting lathe charger.

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[2] Mention of a particular product should not be taken as endorsement by the Forest Service or the U. S. Department of Agriculture.

Lathe.—Logs moved automatically from the lathe charger to a Coe M263 108-inch lathe equipped with Redco automatic controls with operator-option speed control and 3½-inch and 5½-inch dual chucks. The motor was operated at 1,350 rpm, reduced by 4.84 to a 3-inch spindle. Knife bevel was 1¾ inches, knife thickness was ⅝ inch, and knife angle was 90° at 18 inches from the spindle and 88½° at 4 inches from the spindle. The lathe was equipped with a ⅝ inch bronze whipple roller nose bar, 12/32 inch from the center to the knife. The horizontal opening from the surface of the roller bar to the knife edge was 0.110 to 0.115 inch. The lathe was set to cut 0.126 inch veneer. Chuck pressure was set at 450 p.s.i. holding pressure. The logs were peeled at an average of 1.7 logs per minute.

Tray system.—A Redco 5-deck, 120-foot-long tray system was charged by an operator-option manual or automatic tipple. Normally, the roundup waste is dropped through a gate in front of the tipple onto a conveyor that feeds the chipper, and green defect clippings are returned to this conveyor by a belt extending from the end of the grading table under the tray system back to the chipper conveyor. However, because the plant could not permit hardwood chips in their pine chip system, the gate was kept closed, and all roundup material was moved with the veneer through the tray system and was discharged over the end of the grading table. This caused considerable delay in the green-line production and frequently interrupted the veneer flow. In order to obtain accurate log-peeling times, downtime due to these interruptions was recorded and applied to the peeling-rate calculations.

Green clipper.—The green veneer was discharged from the trays over fixed unloader aprons, controlled by auto-magnestats, to an automatic Elliott Bay 108-inch clipper. The clipper was set to clip 54-inch and 27-inch widths and had operator over-ride controls to salvage random widths of usable veneer 6 inches and wider.

Green sorting table.—Clipped veneer passed over a 60-foot-long sorting table at 220 f.p.m.; the veneer was sorted to full-size sheets, 27-inch sheets, and random-width strips. All green waste was discharged over the end of the table and collected for weighing.

Dryer.—Green veneer was transferred by fork truck from the sorting-table stack to dead-roll cases in front of the dryer loader. A Coe 16-section, 4-line, steam-heated, jet-type dryer was charged with veneer by a Coe automatic loader that was hand-charged from the dead-roll cases.

The dryer temperature ranged from 385°F. at the green end to 360°F. at the dry end. Drying time required to attain 4- to 6-percent moisture content was 16 minutes. Thickness and width was measured at random on 10 full-size sheets before and after drying (table 1).

Dry-grading line.—The veneer passed from the dryer through a cooling section and was discharged by a Coe unloader onto a dry-grading table. All veneer was passed through a Laucks-Sentry bar-type moisture detector. Veneer with more than 6-percent moisture content was marked automatically for redrying.

The dry veneer was separated into stacks of faces (grade C and better); full size sheets for backs and cores (grade D); full-length strips, 27 inches wide; fish tails and random-width strips; and cull. The veneer was graded according to U.S. Product Standard PS 1-66 for softwood plywood, except that veneer better than grade C was not segregated.

Table 1.—*Results of veneer shrinkage tests*

Sample No.	Species of oak	Thickness			Width		
		Green	Dry	Shrinkage	Green	Dry	Shrinkage
		Inches	*Inches*	*Percent*	*Inches*	*Inches*	*Percent*
1	Red	0.142	0.130	8.5	$54\frac{1}{2}$	$51\frac{1}{8}$	6.2
2	Chestnut	.134	.118	11.9	$53\frac{7}{8}$	$50\frac{5}{8}$	6.1
3	Chestnut	.133	.125	6.0	$53\frac{1}{2}$	$49\frac{5}{8}$	7.3
4	Chestnut	.136	.120	11.8	$54\frac{1}{16}$	$50\frac{1}{16}$	7.6
5	White	.136	.123	9.6	$54\frac{1}{8}$	$49\frac{7}{8}$	7.9
6	White	.124	.114	8.1	$54\frac{7}{8}$	$51\frac{3}{8}$	6.5
7	Red	.144	.137	4.9	$54\frac{7}{8}$	$51\frac{3}{4}$	6.0
8	Red	.140	.129	7.9	$54\frac{1}{2}$	$51\frac{1}{4}$	6.0
9	Chestnut	.140	.132	12.9	$54\frac{1}{4}$	$51\frac{1}{2}$	5.1
10	Chestnut	.136	.133	2.2	56	$50\frac{1}{2}$	11.6

Glue line.—All grade C and better veneer was moved by fork truck to the lay-up line along with the grade D backs and cores. The balance of usable veneer was cut into ½-inch-long pieces by a Globe band saw, for crossbands. All crossbands were transferred to the glue line by fork truck.

Crossbands were fed through a Globe glue spreader (40-durometer rubber rolls with 9- and 11-thousandth-inch grooving) to the lay-up line.

Crossbands were coated with Reichhold's phenolic-resin-based adhesive mix at the rate of 83 pounds per thousand square feet of double glue line, according to the following formula:

2,500	pounds Reichhold plyophen
718	pounds water
400	pounds furafil
150	pounds wheat flour
125	pounds 50-percent caustic solution
20	pounds soda ash

This formula was selected from 18 different phenolic formulations that were tested previously at the Reichhold Chemicals Company laboratory. Seventy-three panels were tested using the various mixes at a variety of press-cycle, glue-spread, and assembly-time specifications (table 2).

Lay-up.—The veneer was laid up manually into ⅜-inch, ½-inch, ⅝-inch, and ⅞-inch panels (table 3).

Pre-press.—The panels were moved manually over roll conveyors to a Globe hydraulic pre-press and were pressed at 150 p.s.i.

Hot press.—Panels were moved to the hot-press loading elevator over roll conveyors and were loaded manually into a Williams White, hydraulic-operated, steam-heated, 36-opening hot press. The panels were pressed at 200 p.s.i. with platen temperatures of 310°F. (table 3).

Test samples.—After the panels were unloaded automatically from the hot press, the top and bottom layer of each load was marked for test samples. Samples were tested for glue-line quality at the American Plywood Association (A.P.A.) laboratory according to PS 1-66 standards for construction-grade softwood plywood.

Table 2.—*Abbreviated results from laboratory tests for glue-line quality*

Glue No.[1]	No. of panels	Glue spread[2] (double glue line)	Assembly time[2]	Press cycle	Temp.	Press	Shear[2,3]	Wood failure[2,3]	Species	Moisture content
		Lbs./M sq. ft.	*Min.*	*Min.*	*°F.*	*P.s.i.*	*P.s.i.*	*Percent*	*Oaks*	*Percent*
22-398	4	71	15	7½	290	200	296	65	Mixed	5 to 6
22-398+	6	67	18	7½	290	200	278	66	White	5 to 6
EPH2551	9	85	20	7½	290	200	221	32	White	5 to 6
EPH2601	9	76	17	8	290	211	281	69	White	5.6
EPH2500	5	80	60	8	290	225	253	66	White	5 to 6
EPH2551	5	80	18	7½	310	225	290	71	Mixed	5 to 6
E2148	1	80	15	7½	310	225	338	76	White	5 to 6
26-6000	3	80	15	7½	310	225	412	57	Chestnut	5 to 6
EPH2500	5	80	15	7½	310	225	295	70	Mixed	5 to 6
EPH2551	8	80	15	7½	310	225	307	67	Mixed	6 to 7
EPH2551	6	80	20	7½	310	225	270	51	Chestnut	6 to 7
EPH2551	4	86	10	7½	310	225	256	66	Chestnut	3
100R22-01	1	83	10	7½	310	225	309	78	Chestnut	6.8
EPH2501	4	83	10	7½	310	225	276	38	Chestnut	4.4

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[1] All numbers are Reichhold Chemicals Company's designation for specific southern pine phenolic adhesive formulation. Duplicate numbers have different mix proportions.

[2] Figures are average for the panel numbers indicated.

[3] Panels were tested by vacuum-pressure method as described in PS 1-66 standards for exterior glue-line quality.

Table 3.—*Panel assembly and press specifications*

No. of panels	Glue-spread (double glue line)	Total assembly time	Hold time	Pre press time	No. of plies	Panel thickness	Hot press	Hot press time
	Lbs./M sq. ft.	*Min.*	*Min.*	*Min.*		*Inches*	*Psi-°F.*	*Min.*
16	83	8	0	0	5	5/8*	200-310	9
15	83	14	0	0	5	5/8	200-310	9
20	83	22	3	4	5	5/8**	200-310	9
23	83	21	3	4	5	5/8	200-310	9
20	83	20	7	4	5	5/8	200-310	9
19	83	19	4	4	4	1/2	200-310	7
12	83	20	12	0	4	1/2	200-310	7

*Included two 3/8-inch, 3-ply panels.
**Included one 7/8-inch, 7-ply panel.

Trim and grading line.—The panels were moved by fork truck from the hot press to a Cardwell feeder and automatically fed through a Cardwell panel sizing and grading system equipped with Globe trim and skinner saws.

Packaging.—Finished panels were banded for shipment by an Interlake strapping machine.

LOG YIELDS

The sample logs scaled 3,567 board feet, Doyle scale; or 4,933 board feet, International 1/4-inch scale. The yield of usable veneer was 222 cubic feet, the equivalent of 2.18 square feet of 3/8-inch panels per board foot of log input, Doyle scale; or 1.50 square feet of 3/8-inch panels per board foot of log input, International 1/4-inch scale.

It should be noted that the average diameter of the sample logs was only 11.7 inches as compared to the estimated average 13.1-

Table 4.—*Log yields*

Item	Actual[1]		Recalculated[2]	
	Volume	Scaled volume	Volume	Scaled volume
	Cu. ft.	*Percent*	*Cu. ft.*	*Percent*
Scaled input	678	—	840	—
Yield output:				
Green waste[3]	442	65	373	44
Dry waste[4]	144	21	183	22
Veneer	222	33	409	49
Total output[5]	808	—	965	—

[1] Yield from pilot test using 8½-foot logs with an average diameter of 11.7 inches peeled on an 8½-foot lathe.

[2] Computed yield using 8½-foot logs with an average diameter of 13.4 inches peeled on an 8½-foot lathe, and cores repeeled on a 4½-foot lathe (see appendices 3, 4, and 5 for calculations).

[3] Green waste includes all chippable waste—cores, taper, roundup, and green clippings.

[4] Dry waste includes shrinkage, degrade veneer, fishtail ends, spreader rejects, and trim waste.

[5] Total output exceeds scaled input because log-taper volume is not included in scale input. Taper volume was 130 cubic feet or 19 percent of the actual scaled input and 15 percent of the recalculated input, and this volume is included in green waste.

inch diameter of grade 3 Appalachian oaks[3] (see appendix 2). Therefore, additional veneer yield could be expected from a more representative sample of grade 3 oak logs. Additional veneer yield could have been obtained by repeeling cores above 6 inches in diameter in a 4½-foot lathe. With this additional yield, the yield relationship becomes 2.83 square feet of ⅜-inch plywood per board foot of log input, Doyle scale; or 2.08 square feet per board foot of log input, International ¼-inch scale.

Green chippable waste—including material from roundup, defect clippings, cores, and taper—accounted for 65 percent of the scaled cubic input volume. A comparison of actual log yields and recalculated yields is shown in table 4.

A tabulation of data collected is shown in appendix 3, an analysis of data from field results is shown in appendix 4, and an analysis of recalculated data is shown in appendix 5.

THE PLYWOOD PRODUCT

Finished plywood from the pilot test consisted of:

4- by 8-foot panels (No.)	*Thickness (inch)*	*Plys (No.)*
1	⅞	7
91	⅝	5
31	½	4
2	⅜	3

Because of the way oaks branch, the knots occurred in an alternate pattern over the faces and backs of the panels as compared to the strip pattern that occurs in pine plywood from whorled branches (fig. 1). End splits occurred in nearly all the oak panels, because of end checking of the sample logs while in storage. However, these splits did not exceed those allowed in the PS 1-66 standards for C-D softwood plywood.

Two of the panels were sanded, grooved, and finished with

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[3] Diameter distribution data from USDA Forest Service Research Paper FPL-63, June 1966: tables 21, 27, and 33.

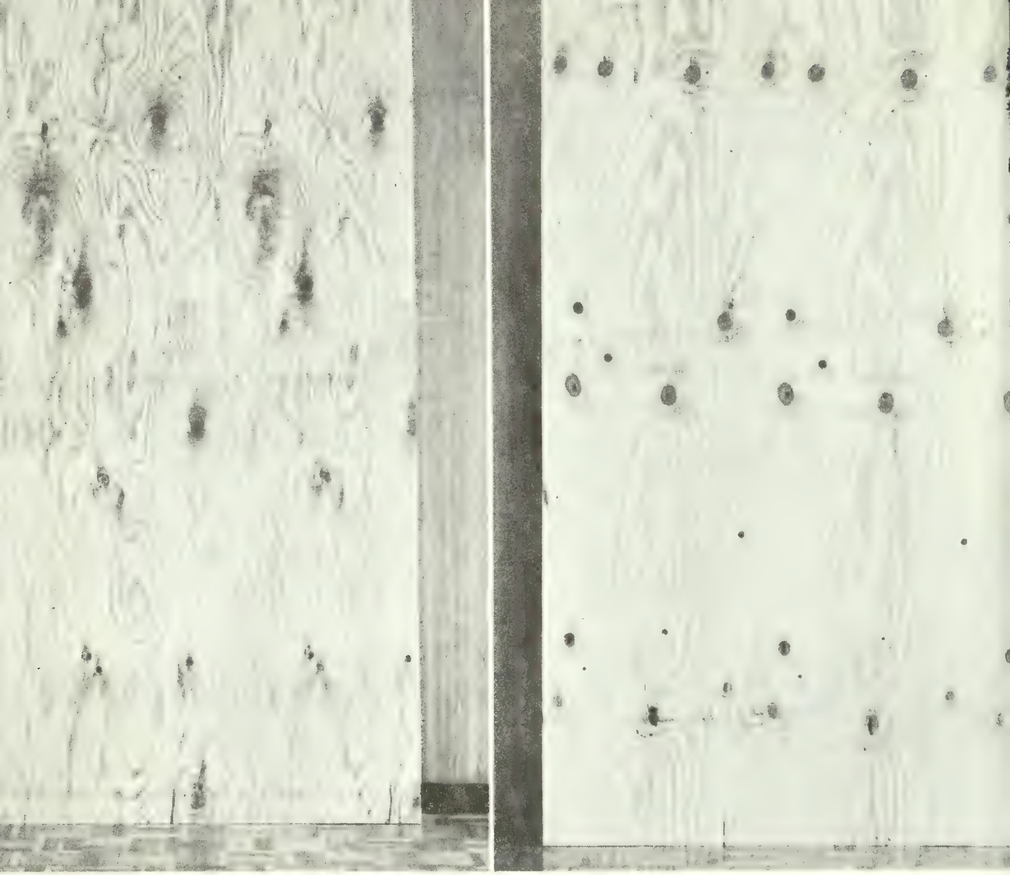

Figure 1.—Grade D back of a typical oak test panel *(left)*, and grade D back of a typical southern pine panel *(right)*.

sealer and lacquer as examples of character-marked interior paneling (fig. 2).

Twenty-five of the ⅝-inch panels were used for top decks on 50 experimental 48- by 40-inch notched stringer warehouse pallets (fig. 3). These pallets meet the specifications of the Grocer Manufacturers of America and the National Wooden Pallet and Container Association's specifications for grade AA pallets. All 50 pallets were stored outside to evaluate the effect of weather on the oak plywood. After 9 months of exposure, no serious deterioration had been noted. These pallets will be included in an experimental program to palletize bulk mail in shipping routes between Dayton, Ohio, and Springfield, Massachusetts. All pallets are labeled so that an accurate record of the field performance of each unit can be recorded.

The remaining panels will be used for roof sheathing and siding on an experimental storage building and a lumber dry kiln control room at the Forest Products Marketing Laboratory at Princeton, West Virginia.

None of the panels tested met wood failure requirements after

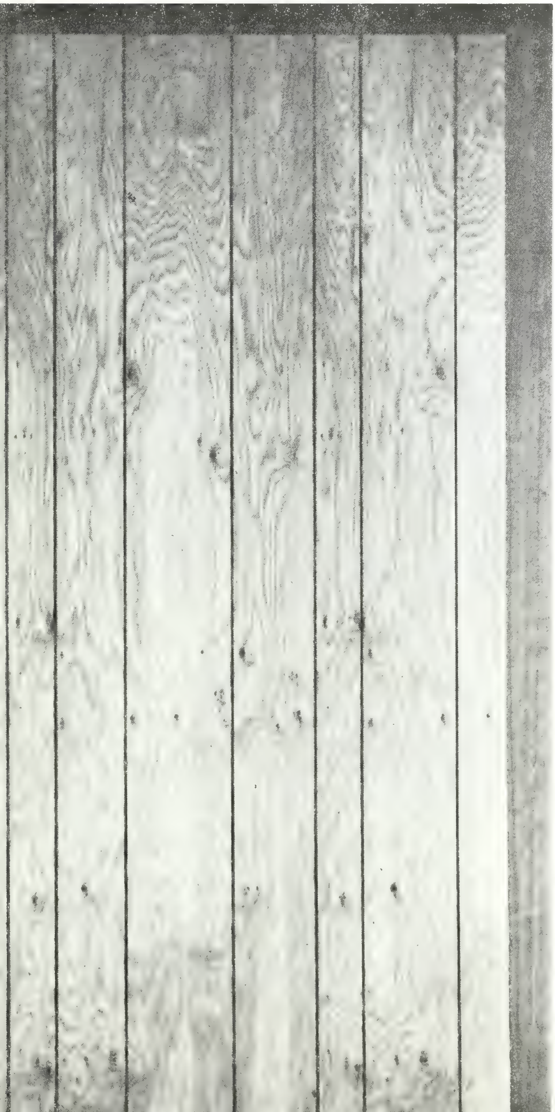

Figure 2.—Grade C face of an oak panel that was sanded, grooved, and finished with sealer and lacquer.

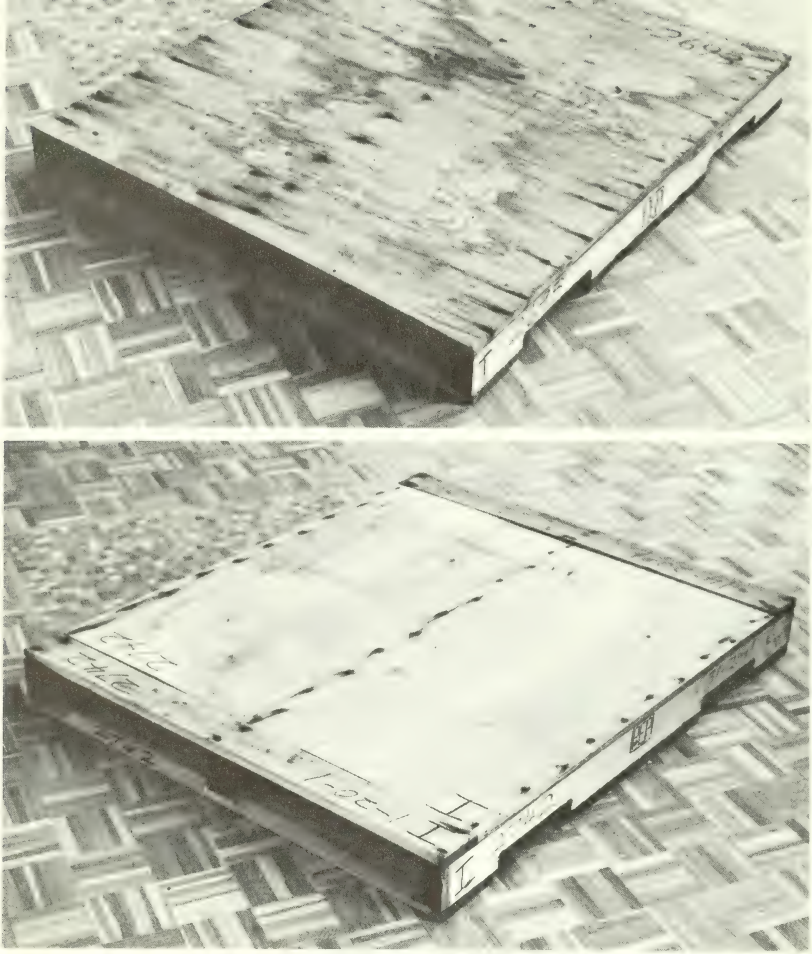

Figure 3.—Full oak plywood deck *(top)*, and an oak plywood deck in combination with a lumber edge *(bottom)* on 40- by 48-inch notched stringer pallets.

being subjected to the vacuum pressure, soak test as prescribed under paragraph 4.42 of the PS 1-66 standards for construction grade softwood plywood. Wood failure ranged from 0 to 27 percent (average for five individual exterior shear samples). Both of these extremes were for panels that failed at loads of 200 pounds per square inch. Eighty-percent wood failure is required by PS 1-66 standards. Load failure for all the sample panels ranged from 100 to 250 pounds per square inch.

Many of the laboratory specimens (table 3) exceeded the requirements for a waterproof bond as described in the CS 35-61 standards for hardwood plywood, but these standards are not applicable to construction-grade plywood.

The adhesives used did not duplicate earlier laboratory results (table 2), nor did they meet the requirements of either CS 35-61 hardwood standards or PS 1-66 softwood standards for exterior-type glue line.

Until appropriate standards are developed for construction-grade hardwood plywood, and a low-cost waterproof adhesive is developed for oak, construction-grade oak plywood would be restricted to interior use. It is expected that this problem will not exist with the less-dense hardwood species.

USES FOR HARDWOOD PLYWOOD

Because of the wide range in density of hardwoods, the plywood product can be divided into two density groups. The group of higher density includes oak, hard maple, ash, hickory, birch, cherry, sycamore, gum, and elm. Potential uses for the construction grade plywood from this group are sheathing, subflooring, concrete forms, pallet decks, framing for upholstered furniture, furniture backs, truck floors, heavy industrial crating, and other uses where nail-holding capacity, resistance to abrasion, resistance to splitting, and toughness are important.

Construction-grade plywood from the species of lower density, such as poplar, basswood, aspen, cucumber, and soft maple, could be used for roof and side sheathing, underlayment, truck and boxcar linings, cable reels, and other uses where light weight is important. A combination of dense faces and less dense interplys and backs might be used where characteristics of the dense species are desirable and weight is a factor. However, a set of standards for glue-line quality, applicable to hardwood plywood, should be developed before marketing these products.

A smaller market might exist for decorative paneling where character marks, unusual grain patterns, or a rustic or barn-board appearance is desirable.

PRODUCTION-PLANT ESTIMATES

In this study, the proposed plant size for the production of construction-grade hardwood plywood was based on a survey of raw-material supply within an economic hauling distance of four selected areas of West Virginia (appendix 1). It was found that a plant capable of using about 12 million board feet of grade 3 logs annually could be supplied with raw material at three of the selected locations.

An automated plywood plant capable of consuming 12 million board feet of raw material would produce about 35 million square feet of ⅜-inch plywood per year. A plant of this size was opened in May 1966 by Weldwood of Canada at Longlac, Ontario. This plant produces construction-grade plywood from Canadian aspen. It is highly automated and operates with 22 production personnel per shift. The advertised cost of this plant, fully equipped, was $1,500,000. The estimated cost of a similar plant—quotations from U.S. manufacturers (1966 prices)—is within $100,000 of this cost.

In this study, the initial investment in the physical plant and

Table 5.—*Estimated annual costs of operating a 1.5-million-dollar utility grade hardwood plywood plant*[1]

Item of cost	Based on pilot test yield[2]	Based on recalculated yield[3]
Logs	$ 912,240	$ 641,340
Adhesive	226,800	226,800
Utilities	136,836	96,201
Direct operating labor	308,880	308,880
Direct supervision	30,888	30,888
Payroll overhead	49,421	49,421
Investment-related costs	150,000	150,000
Selling and management	272,260	255,529
Total annual operating costs	$2,087,325	$1,729,059

[1] Costs determined using Coolidge and Pfeiffer system for estimating cost.
[2] See appendix 6 for calculations.
[3] See appendix 7 for calculations.

Table 6.—*Annual break-even production cost estimates for operating a utility-grade hardwood plywood plant*

Item	Based on pilot test yield	Based on recalculated yield
A. Operating cost[1] .... dollars	2,087,325	1,729,059
B. Production of 5/8-inch plywood. . M sq. ft.	22,680	22,680
C. Chip production .... tons	77,607	34,170
D. Chip revenue[2] .... dollars	388,035	170,850
E. Net operating cost (A-D) .... dollars	1,699,290	1,558,209
F. Break-even cost (E/B)[3] .... dollars	74.92	67.82

[1] See table 5.

[2] At $5 per ton.

[3] Per 1000 sq. ft. of 5/8-inch plywood.

the required production force was assumed to be equal to that for the Longlac plant.

The price of grade 3 logs, as published by those sawmills in West Virginia that buy logs by grade, ranges from $25 to $50/M board feet, Doyle log scale. Woods-run logs range in price from $45 to $65/M board feet, Doyle log scale. For our cost estimates, the price for grade 3 logs was assumed to be $50/M board feet, Doyle log scale, for logs 8 feet long with a 6-inch trim allowance.

We used the system of estimating cost for wood industries developed by Coolidge and Pfeiffer. The actual yields from the pilot test were used for calculations in appendix 6. The calculated yields were used for the estimates in appendix 7. Results from these calculations are compared in tables 5 and 6.

SUMMARY

A study was conducted in the fall of 1968 to determine the feasibility of producing a construction-grade plywood from grade 3 oak logs.

Facilities of a typical automated southern-pine sheathing plant were used for the test; and no basic changes were made in the production process or machinery from that used for pine-sheathing production.

Actual test production (in percent of scaled volume)—from an input volume scaled at 668 cubic feet—was as follows: usable grade C and D veneer, 33 percent; green chippable waste including cores, 45 percent; dry waste, 22 percent; additional chippable green waste (not included in scaled volume) resulting from log taper, 147 cubic feet or 22 percent.

The average diameter of the sample of logs was 11.7 inches. The average diameter of grade 3 oak logs in the Appalachians is 13.17 inches. By calculating the additional veneer that could be expected from the larger diameters and the additional veneer obtained by repeeling cores 6 inches and larger on a 4½-foot lathe, the production (in percent of scaled volume)—from an input volume scaled at 840 cubic feet—was as follows: usable grade C and D veneer, 50 percent; green chippable waste including cores, 27 percent; dry waste, 23 percent; and additional green waste from log taper, 18 percent.

A phenolic adhesive formulation similar to that used for pine was used for the test. Test panels failed to meet the required PS 1-66 vacuum pressure-soak test. This indicates that an oak utility-grade plywood could not compete in a market where an exterior glue is required.

When the test results are applied to a plant operating-cost system, as developed by Coolidge and Pfeiffer in their "Cost Estimating for Wood Plants," the break-even cost for producing ⅝-inch C-D plywood—in a plant with an initial investment of $1,500,000—is about $75 per M square feet. When the results from recalculated yield data are applied to the same system, the break-even cost for producing C-D grade plywood was reduced to about $68 per M square feet of ⅝-inch plywood.

CONCLUSIONS

Veneer of the quality required for C-D construction-grade plywood can be cut from grade 3 oak logs. Plant systems used for production of pine plywood are readily adaptable to production of oak plywood. Production machinery is available from existing manufacturers' models. The only appreciable difference in machinery requirements is that production of oak plywood would require about 40-percent more dryer capacity than is required for production of pine plywood.

The adhesives evaluated were similar to those used in the manufacture of southern pine sheathing-grade plywood. Unfortunately, the adhesives used did not duplicate earlier laboratory results, nor did they meet the requirements of either CS 35-61 hardwood standards or PS 1-66 softwood standards for exterior-type glue line. Further research for a suitable low-cost adhesive was indicated. Cost estimates for this report were made on the assumption that such an adhesive can be developed.

Based on 1966 machinery and construction prices and the current wholesale price for softwood sheathing, profits in excess of 50 percent per invested dollar before income taxes could be expected from such a hardwood plywood venture.

There is a need for further research to (1) determine veneer yields by grade for oak and the other commercial grade 3 hardwood species, (2) determine the economic diameter limit for hardwood veneer production, (3) examine the market acceptance of hardwood construction-grade plywood, and (4) develop appropriate glue-line standards for construction-grade hardwood plywood.

■

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Table 7.—*Available grade 3 oak sawtimber for new industry in selected areas of West Virginia*[1]

[In million board feet]

Selected area[2]	One-half annual growth[3]*	Annual cut[4]*	Unused growth[5]*	Unused growth[5]**	One-half inventory[3]*	One-half inventory[6]**	Annual available inventory over—	
							20 yrs.**	30 yrs.**
Beckley	25.7	9.0	16.7	12.9	888.9	684.5	34.2	22.8
Huntington	5.8	1.2	4.6	3.5	168.0	129.4	6.5	4.3
Elkins	18.7	6.0	12.7	9.8	734.0	565.2	28.3	18.5
Richwood	18.9	7.7	11.2	8.6	689.0	530.5	26.5	17.7

[1] Basic data were taken from TIMBER INDUSTRY OPPORTUNITIES IN SELECTED AREAS OF WEST VIRGINIA by Perry Hagenstein, 1964; tables 3, 19, 27, 35, and 51.

[2] Within a 50-mile radius.

[3] One-half of the growth was assumed to be inaccessible or unavailable. Grade 3 growth was taken as 45 percent of total growth from THE TIMBER RESOURCE OF WEST VIRGINIA by Roland H. Ferguson, 1964.

[4] Grade 3 cut was taken as 5/9 of 30 percent of the total cut from THE TIMBER RESOURCE OF WEST VIRGINIA by Roland H. Ferguson, 1964.

[5] Unused growth = difference between grade 3 growth and grade 3 cut.

[6] International ¼-inch scale was converted to Doyle scale by multiplying the International ¼-inch volume by 0.77. The multiplier was found by comparing International ¼-inch volume to Doyle volume for 300 logs of the diameter distribution shown in appendix 2.

*International ¼-inch log scale.

**Doyle log scale.

APPENDIX 2

Table 8.—*Species distribution by diameter*

Diam.[1] (in.)	Species distribution for the 105-log sample			Diam.[1] (in.)	Desired species distribution for 105 logs[2]		
	White oak	Red oak	Chestnut oak		White oak	Red oak	Chestnut oak
8	0	0	4	8	1	2	1
9	1	0	4	9	4	3	4
10	1	4	20	10	5	7	4
11	3	3	12	11	5	2	4
12	3	4	15	12	5	4	3
13	4	2	10	13	3	3	4
14	0	1	4	14	2	3	3
15	0	1	4	15	3	2	2
16	0	0	2	16	2	3	1
17	0	0	0	17	0	1	1
18	0	0	1	18	1	1	2
19	1	0	0	19	1	1	2
20	0	0	1	20	1	0	2
21	—	—	—	21	0	1	—
22	—	—	—	22	1	1	—
23	—	—	—	23	—	0	1
24	—	—	—	24	—	1	1
25	—	—	—	25	1	—	—
Total	13	15	77	Total	35	35	35

[1] D.i.b. at small end.

[2] Diameter distribution for upland grade 3 oaks taken from USDA Forest Service Research Paper FPL-63, June 1966.

APPENDIX 1

Data From Pilot Test

I. Scaled input volume	
A. 105 logs, 8.5 feet long x 11.7 average d.i.b. at the small end	668 cu. ft.
II. Yields	
A. Green waste	
1. Cores	224 cu. ft.
2. Roundup and defect clippings (weight of all green veneer waste = 14,150 pounds, oak @ 80 percent moisture content weighs 65 pounds/cu. ft.)	
Total roundup + clipping waste = $\frac{14{,}150}{65}$	218 cu. ft.
3. Total waste for chip production (224 + 218)	442 cu. ft.
B. Dry waste (including shrinkage)	
1. Degrade veneer stack ($1\frac{1}{6}$ ft. x $4\frac{1}{2}$ ft. x $8\frac{1}{2}$ ft.) =	44.6 cu. ft.
2. Fishtail end stack ($2\frac{1}{3}$ ft. x $4\frac{1}{2}$ ft. x $4\frac{1}{4}$ ft.) =	44.6 cu. ft.
3. Spreader reject stack (11/12 ft. x $4\frac{1}{2}$ ft. x $4\frac{1}{4}$ ft.) =	17.5 cu. ft.
4. Trim:	
a. Rough panels ($8\frac{1}{2}$ ft. x $4\frac{1}{2}$ ft. x $6\frac{1}{6}$ ft.)	235.9 cu. ft.
Less finished panels (8 ft. x 4 ft. x $6\frac{1}{6}$ ft.)	197.3 cu. ft.
Net panel trim =	38.6 cu. ft.
b. Rough unused veneer (19/24 ft. x $4\frac{1}{2}$ ft. x $8\frac{1}{2}$ ft.)	30.3 cu. ft.
Less trimmed veneer (19/24 ft. x 4 ft. x 8 ft.)	25.3 cu. ft.
Net unused veneer trim =	5.0 cu. ft.
5. Total dry waste (44.6 + 44.6 + 17.5 + 38.6 + 5.0) =	150.3 cu. ft.
C. Usable veneer	
1. Panel stack (4 ft. x 8 ft. x $6\frac{1}{6}$ ft.)	197.3 cu. ft.
2. Unused veneer stack (19/24 ft. x 4 ft. x 8 ft.)	25.3 cu. ft.
3. Total veneer yield (197.3 + 25.3)	222.6 cu. ft.
III. Taper (over-run)	
A. Log taper was not included in scaled volume. Therefore, total yied exceeds scaled input.	
1. Total yield minus scaled input = taper volume (442 + 150 + 223) — 668 =	147. cu. ft.

APPENDIX 4

Data Anaylsis: *Based on Pilot Test Yields*

I. Yields (based on actual production test results expressed as a percentage of scaled volume input)

A. Usable veneer

$\frac{197 \text{ cu. ft.}}{668 \text{ cu. ft. input}} =$ 29%

2. Leftover usable veneer (less trim)

$\frac{25 \text{ cu. ft.}}{668 \text{ cu. ft. input}} =$ 4%

3. Total veneer yield (29 + 4) 33%

B. Core volume

1. $\frac{224 \text{ cu. ft.}}{668 \text{ cu. ft. input.}} =$ 34%

C. Green waste not including cores and taper

1. Roundup and green clippings

Total green waste	218 cu. ft.
Less taper waste	147 cu. ft.
	71 cu. ft.

$\frac{71 \text{ cu. ft.}}{668 \text{ cu. ft. input}} =$ 11%

D. Dry waste

1. Fishtails, degrade veneer, spreader rejects and trim . . . . 150 cu. ft.

2. $\frac{150 \text{ cu. ft.}}{668 \text{ cu. ft.}} =$ 22%

E. Chippable waste for revenue

1. Cores . . . . 224 cu. ft.

2. Green waste (including taper waste) . . . . 218 cu. ft.

Total . . . . 442 cu. ft.

$\frac{442 \text{ cu. ft.}}{668 \text{ cu. ft.}} =$ 66%

APPENDIX 5

Data Analysis: Based on Recalculated Yields

I. Justification

A sheathing plant for the production of hardwood plywood should be equipped with both 8½- and 4½-foot lathes. The 4½-foot lathe would be used for peeling short straight sections from logs with excessive sweep and for repeeling large cores dropped at the 8½-foot lathe. The test plant used was not equipped with a 4½-foot lathe, therefore the additional veneer available from repeeling all cores 6 inches in diameter and above is considered as usable veneer yield in the recalculated data analysis.

Additional yield expected from the cutting of logs with excessive sweep into 4½-foot lengths rather than 8½-foot lengths before peeling is not considered in this analysis.

The average diameter of the logs used in the test was 11.7 inches. The average diameter of grade 3 oak logs in the Appalachians is 13.14 inches. Therefore, the additional veneer expected as a result of the larger diameter is considered in the calculated data analysis.

II. Scaled input volume

A. 105 total logs x (vol. of 13.14-inch diam. by 8½-foot long log) = ... 840 cu. ft.

B. 105 total logs x (vol. of 11.7-inch diam. by 8½-foot long log) = ... 668 cu. ft.

C. $\frac{840 \text{ cu. ft.}}{668 \text{ cu. ft.}}$ = percent calculated vol. of actual volume = ... 126%

III. Yields (expressed as percent of scaled volume)

A. Usable veneer

1. Repeeled cores 4½ feet long

Diam. (in.)	*Volume (cu. ft.)*		*4 in. diam. core volume (cu. ft.)*		*Veneer vol. per core (cu. ft.)*		*Cores (No.)*		*Salvaged veneer (cu. ft.)*
6	0.88	—	0.39	=	0.49	x	25	=	12.25
7	1.20	—	.39	=	.81	x	7	=	5.67
8	1.57	—	.39	=	1.18	x	18	=	21.24
9	1.99	—	.39	=	1.59	x	10	=	15.90
10	2.45	—	.39	=	2.06	x	7	=	14.42

Total rough veneer = ... 69.48 cu. ft.

Trim (16.3% of 69.48)............ 11.33 cu. ft.

Total salvaged veneer from cores (69.48 — 11.33) .... 58.15 cu. ft.

2. Diameter adjustment			
Scaled volume from 13.14-inch diam. logs			840 cu. ft.
Scaled volume from 11.7-inch diam. logs			668 cu. ft.
Additional volume of rough veneer (840-668)			172 cu. ft.
Less trim (16.3% of 172)			28 cu. ft.
Net usable veneer (172-28)			144 cu. ft.
3. Panel volume from 11.7-inch diam. logs			197 cu. ft.
4. Unused veneer from 11.7-inch diam. logs			25 cu. ft.
5. Total usable veener (58 + 144 + 197 + 25)			424 cu. ft.
6. Percent of scaled volume $\left(\frac{424}{840}\right)$			50 percent
B. Dry waste			
1. Trim (including shrinkage)			
Total trim			
a. From test results	44 cu. ft.		
b. From repeeled cores	11 cu. ft.		
c. From diameter adjustment	28 cu. ft.		
Total trim (44 + 11 + 28)		83 cu. ft.	
2. Degrade veneer		45 cu. ft.	
3. Fishtail ends		45 cu. ft.	
4. Spreader reject veneer		17 cu. ft.	
Total dry waste (83 + 45 + 45 + 17)			190 cu. ft.
Percent of scaled volume $\left(\frac{190}{840}\right)$			23 percent
C. Green waste			
1. Cores (224 cu. ft. less 69 cu. ft. of salvaged veneer)			155 cu. ft.
2. Taper waste (from 11.7-inch diam. logs)			147 cu. ft.
3. Net roundup and defect clippings (218-147)			71 cu. ft.
Total green waste (155 + 71)			226 cu. ft.
4. Percent of scaled volume $\left(\frac{226}{840}\right)$			27 percent
D. Chippable waste for revenue			
1. Cores (155) + roundup (71) + taper (147)			373 cu. ft.
2. Percent of scaled volume $\left(\frac{373}{840}\right)$			41 percent

APPENDIX 6

Estimate of Annual Operating Costs and Profits For a Utility Grade Hardwood Plywood Plant Based on Pilot Test Yields

ANNUAL LOG COSTS

Production Requirements

30,000 sq. ft. of ⅝-inch thick, five-ply plywood per 8-hour shift, or 90,000 sq. ft. per 3-shift day.

Log Volume Requirements

Average log = 12-inch d.i.b. by 8-foot long (with 6-inch allowance for chucking and trim.)*

Average log volume = $\pi r^2 L = \pi \times \left(\frac{6}{12}\right)^2 \times 8 = 6.28$ cu. ft.

Amount of ⅛-inch veneer per average log = 6.28 cu. ft. x 8 x 12 = 602.88 sq. ft.

Assuming 67-percent waste in processing logs into plywood, the net yield of ⅛-inch veneer per average log = 602.88 sq. ft. x .33 = 198.95 sq. ft.

Daily requirements for ⅛-inch veneer = 90,000 (sq. ft.) x 5 (ply) = 450,000 sq. ft.

Daily log requirements = $\frac{450{,}000 \text{ (sq. ft.)}}{198.95 \text{ (sq. ft./log)}}$ = 2,261 logs per day.

Each log contains 32 board feet (Doyle log scale).

Daily log volume requirement = 2,261 logs x 32 = 72,352 board feet, Doyle scale.

Daily log cost @ $50 per M board feet, Doyle scale = $50 x 72.4 = $3,620.

Annual log cost = $3,620 x 252 days = $912,240.

ESTIMATE OF ANNUAL REVENUE FROM CHIPS

A. Annual log volume as weight input.

2,261 logs per day x 252 days = 569,772 logs/year.

11.71-inch diameter x 8.5-foot long logs = 0.7466 sq. ft. x 8.5 ft. = 6.35 cu. ft./log.

6.35 x 569,772 = 3,618,052 cu. ft. input/year.

$\frac{3{,}618{,}052 \text{ cu. ft. x } 65 \text{ lbs./cu. ft.}}{2{,}000 \text{ lbs.}}$ = 117,587 tons input/year.

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*Trim allowance is not included in veneer-yield and log-volume calculations because (1) the veneer is trimmed to a net width of 8 feet; and (2) trim allowance is not included in board-foot log scale calculations. However, trim allowance is included in cubic volume input-output calculations because green trim waste is actually part of chippable refuse.

B. Annual chip production.
From appendix 4, green waste for chips = 66% of scaled volume.
117,587 tons x 66% = 77,607 tons/year.

C. Revenue from chips
77,607 tons @ $4.00/ton = $310,428.00
77,607 tons @ $5.00/ton = $388,035.00
77,607 tons @ $6.00/ton = $465,642.00
77,607 tons @ $8.00/ton = $620,856.00

ANNUAL PLANT OPERATING COSTS[**]

Total physical plant costs	$ 1,500,000
Rated capacity of plant per shift (sq. ft. of 5/8-inch plywood)	30,000
Estimated shifts per day	3
Expected production days per year	252
Rated capacity of plant per year (sq. ft. of 5/8-inch plywood)	22,680,000
A. Cost of raw materials	
1. Logs	$ 912,240
2. Glue @ $5/double glue line/1,000 ft. (2 double lines per 5-ply panel)	$ 226,800
B. Utilities (15 percent of log costs)	$ 136,836
C. Direct operating labor (66 persons @ $2.25 per hour and 260 paid days per year)	$ 308,880
Labor-determined costs:	
1. Direct supervision (10 percent of direct labor)	$ 30,888
2. Payroll overhead (16 percent of direct labor)	$ 49,421
Total labor-determined costs	$ 80,309
D. Investment-determined costs. (10 percent of physical plant. Includes general overhead; maintenance and operation supplies; depreciation; taxes; and insurance.)	$ 150,000
Total production costs	$1,815,065
E. Selling and management costs (15 percent of total production costs)	$ 272,260
Total of all operating costs	$2,087,325

PROFIT ESTIMATE[†]

A. Total plant investment (physical plant + initial work capital) (initial working capital = 3 months operating costs)	$2,021,831
B. Estimated annual production (M sq. ft. of 5/8-inch plywood)	$ 22,680

[**] From table 6, page 24 and 25 of Cost Estimating For Wood Plants by L. D. Coolidge and J. R. Pfeiffer.

[†] From table 8, page 35 Cost Estimating For Wood Industries by L. D. Coolidge and J. R. Pfeiffer.

C. Estimated annual sales = (B x expected average selling price) + $388,035 chip sales @ $5.00/ton.
With expected average selling price

@ $70 per M sq. ft.	$1,975,635
80	2,202,435
90	2,429,235
100	2,656,035
110	2,882,835
120	3,109,635
130	3,336,435
140	3,563,235

D. Estimated annual operating costs $2,087,325

E. Net annual revenue or loss before income taxes (C-D)

@ $ 70	$-111,690
80	115,110
90	341,910
100	568,710
110	795,510
120	1,022,310
130	1,249,110
140	1,475,910

F. Profit per invested dollar (E/A)	@ $ 80	$ 0.057
	90	.169
	100	.281
	110	.393
	120	.505
	130	.618
	140	.730
G. Profit per sales dollar (E/C)	@ $ 80	$ 0.052
	90	.141
	100	.214
	110	.276
	120	.329
	130	.374
	140	.414
H. Profit per unit (M sq. ft. produced) (E/B)	@ $ 80	$ 5.08
	90	15.08
	100	25.08
	110	35.08
	120	45.08
	130	55.08
	140	65.08

APPENDIX 7

Estimate of Annual Operating Costs and Profits for a Utility Grade Hardwood Plywood Plant Based on Calculated Yields

ANNUAL LOG COSTS

Production Requirements

30,000 sq. ft., ⅝-inch thick, five-ply plywood per 8-hour shift or 90,000 sq. ft. per 3-shift day.

Log Volume Requirements

Average log = 13-inch d.i.b. by 8-foot long (with 6-inch allowance for chucking and trim).*

Average log volume $= \pi r^2 L = \pi \times \left(\frac{6.5}{12}\right)^2 \times 8 = 7.370$ cu. ft.

Amount of ⅛-inch veneer per average log = 7.37 cu. ft. x 8 x 12 = 707.52 sq. ft.

Assuming 50-percent waste in processing logs into plywood, the net yield of ⅛-inch veneer per average log = 707.52 sq. ft. x 50 = 353.76 sq. ft.

Daily requirements for ⅛-inch veneer = 90,000 (sq. ft.) x 5 (ply) = 450,000 sq. ft.

Daily log requirements $= \frac{450{,}000 \text{ (sq. ft.)}}{353.76 \text{ (sq. ft./log)}} = 1{,}272$ logs per day.

Each log contains 40 board feet (Doyle log scale).

Daily log volume requirements = 1,272 logs x 40 = 50,880 board feet, Doyle scale.

Daily log cost @ $50 per M board feet, Doyle scale = $50 x 50.9 = $2,545.00.

Annual log cost = $2,545.00 x 252 days = $631,340.00.

ESTIMATE OF ANNUAL REVENUE FROM CHIPS

A. Annual log input.

1272 logs per day x 252 days = 320,544 logs per year.

13.14-inch diam. x 8.5-foot long logs = .9417 sq. ft. x 8.5 ft. = 8.0 cu. ft./log.

8.0 x 320,544 = 2,564,352 cu. ft. input/year.

$$\frac{2{,}564{,}352 \times 65 \text{ lbs. per cu. ft.}}{2{,}000 \text{ lbs.}} = 83{,}341 \text{ tons input/year.}$$

---

*Trim allowance is not included in veneer-yield and log-volume calculations because (1) the veneer is trimmed to a net width of 8 feet; and (2) trim allowance is not included in board-foot log scale calculations. However, trim allowance is included in cubic volume input-output calculations because green trim waste is actually part of chippable refuse.

B. Annual chip production.
From appendix 5, green waste for chips = 41 percent of scaled volume.
83,341 x .41 = 34,170 tons/year.

C. Revenue from chips
34,170 tons @ $4.00/ton = $136,680.00
34,170 tons @ $5.00/ton = $170,850.00
34,170 tons @ $6.00/ton = $205,020.00
34,170 tons @ $7.00/ton = $239,190.00
34,170 tons @ $8.00/ton = $273,360.00

ANNUAL PLANT OPERATING COSTS**

Total physical plant costs		$ 1,500,000
Rated capacity of plant per shift (sq. ft. of ⅝-inch plywood)		30,000
Estimated shifts per day		3
Expected production days per year		252
Rated capacity of plant per year (sq. ft. of ⅝-inch plywood)		22,680,000
A. Cost of raw material		
1. Logs		$ 641,340
2. Glue @ $5 per 1,000 ft. of double glue line (2 double glue lines per 5-ply panel)		$ 226,800
B. Utilities (15 percent of log costs)		$ 96,201
C. Direct operating labor (66 persons @ $2.25 per hour and 260 paid days per year)		$ 308,880
Labor determined costs:		
1. Direct supervision (10 percent of direct labor)	$30,888	
2. Payroll overhead (16 percent of direct labor)	$49,421	
Total labor-determined costs		$ 80,309
D. Investment-determined costs (10 percent of physical plant including: general overhead; maintenance and operation supplies; depreciation; taxes; and insurance)		$ 150,000
Total production costs		$ 1,503,530
E. Selling and management costs (15 percent of total production costs)		$ 225,529
Total all operating costs		$ 1,729,059

PROFIT ESTIMATE FOR HARDWOOD UTILITY GRADE PLYWOOD†

(Calculated data ⅝-inch basis)

A. Total plant investment
(physical plant + initial work capital)
(initial working capital = 3 months operating costs) . . . $1,932,265

**From table 6, page 24 and 25 of Cost Estimating For Wood Plants by L. D. Coolidge and J. R. Pfeiffer.

†From table 8, page 35 Cost Estimating For Wood Industries by J. D. Coolidge and J. R. Pfeiffer.

B. Estimated annual production (M sq. ft. of $\frac{5}{8}$-inch plywood)		22,680
C. Estimated annual sales = (B x expected average selling price) + $170,850 chip sales @ $5/ton. With expected average selling price		
	@ $ 70 per M sq. ft.	$1,758,450
	80	1,985,250
	90	2,212,050
	100	2,438,850
	110	2,665,650
	120	2,892,450
	130	3,119,250
	140	3,346,050
D. Estimated annual operating costs		$1,729,059
E. Net annual revenue before income taxes (C-D)		
	@ $70	$ 29,391
	80	256,191
	90	482,991
	100	709,791
	110	936,591
	120	1,163,391
	130	1,390,191
	140	1,616,991
F. Profit per invested dollar (E/A)	@ $ 70	$ 0.015
	80	.133
	90	.250
	100	.367
	110	.485
	120	.602
	130	.719
	140	.837
G. Profit per sales dollar (E/C)	@ $ 70	$ 0.167
	80	.290
	90	.218
	100	.291
	110	.351
	120	.402
	130	.446
	140	.483
H. Profit per unit (M sq. ft.) produced (E/B)	@ $ 70	$ 1.296
	80	11.296
	90	21.296
	100	31.296
	110	41.296
	120	51.296
	130	61.296
	140	71.296

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Dennis Bradley, formerly with the staff of the Forest Products Marketing Laboratory, assisted in the collection and analysis of data for the preparation of a study plan.

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M. D. Shrum and Turner Ross, of the U. S. Plywood Company, interrupted their production schedule so that a well-trained crew, with long experience in the production of plywood, could perform the pilot production test.

Ben Bole and Harry Shieve, of the Coe Manufacturing Company, contributed their time and knowledge of plywood production machinery for a field study of existing production facilities and for supervision of machinery adjustments during the pilot test.

THE FOREST SERVICE of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

A Selected and Annotated BIBLIOGRAPHY of PITCH PINE (*Pinus rigida* Mill.)

by **Silas Little**
Jack McCormick
John W. Andresen

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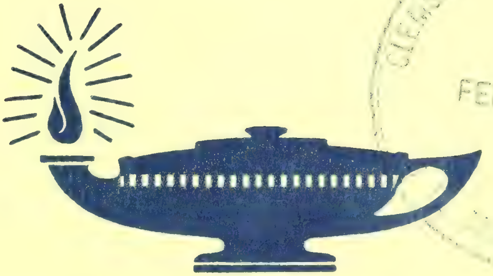

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1970

NORTHEASTERN FOREST EXPERIMENT STATION, UPPER DARBY, PA.
FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
RICHARD D. LANE, DIRECTOR

FOREWORD

THE AUTHORS have attempted to include in this bibliography all articles that contain significant original information about pitch pine or that are comprehensive reviews. Secondary sources, such as textbooks that briefly review the literature on specific subjects, are omitted. Articles on local floras are included only if they provide new, revised, or more detailed information about the distribution or abundance of pitch pine.

The bibliography is undoubtedly incomplete. Significant articles in foreign languages may have escaped our notice—as well as some published in this country. In addition, publications on new research results will soon make this bibliography out of date. The authors will welcome references to articles that should be included in any revision.

The table of contents lists the subjects under which the references have been placed. The arrangement is by (1) subject, (2) author in alphabetical order, and (3) date of publication. Papers that include information on more than one of the subject categories are listed only under the subject most strongly emphasized in the paper. Consequently, users of this bibliography should examine references listed under related subjects for papers that might be pertinent to their interests. For example, references to papers dealing with prescribed burning may be found in four places: (1) in the section on *Silviculture and Management* under *Natural Regeneration;* in the section on *Forest Ecology* under both (2) *Plant Sociology* and (3) *Atmospheric and Biotic Relations:* and (4) in the section on *Forest Damage and Protection* under *Fire.*

To facilitate use of the bibliography, an index of authors is included. This index is arranged alphabetically by authors' surnames and initials, and it lists for each author or co-author the numbers of references included in the bibliography. A few committee reports and government publications are listed under the titles of the organization or committee, but only those in which the principal author is not identified.

Though in the annotations the authors attempted to abstract very briefly the information in each paper, the abstracts are necessarily incomplete.

THE AUTHORS

SILAS LITTLE is a principal silviculturist for the Northeastern Forest Experiment Station, Upper Darby, Pa. He received his B.S. degree from Massachusetts State College and M.F. and Ph.D degrees from Yale University. Since 1936 he has been employed by the USDA Forest Service, mostly on silvicultural and fire research in New Jersey, Maryland, and Pennsylvania. Several of his studies in New Jersey have dealt with pitch pine.

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JOHN W. ANDRESEN is chairman of the Forestry Department of Southern Illinois University, Carbondale. He received his B.S. degree from the New York State University College of Forestry at Syracuse University and his Ph.D. degree from Rutgers University. He taught at Rutgers University and Michigan State University before going to Southern Illinois University. Like McCormick, he became interested in pitch pine while a graduate student at Rutgers University.

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DISTRIBUTION & RESOURCE STATISTICS

Distribution

1. Ashe, W. W.
   1893. **Notes on the forest resources of North Carolina.** J. Elisha Mitchell Sci. Soc. 10: 5-25.
   Pitch pine occurs in Surry, Wilkes, Caldwell, Burke, McDowell, and Polk Counties as well as in the mountain counties south of the French Broad River.

2. Bartholomew, Elizabeth Ann.
   1948. **Flora of Wirt County, West Virginia.** Castanea 13: 145-166.
   Occurrence of pitch pine is mentioned.

3. Besley, F. W.
   1916. **The forests of Maryland.** 152 pp., illus. Md. State Board Forestry.
   Pitch pine occurs in southern, central, and western Maryland, but not on the Eastern Shore.

4. Bicknell, Eugene P.
   1908. **The ferns and flowering plants of Nantucket.** Torrey Bot. Club Bull. 35: 49-62.
   Pitch pine is the most abundant and conspicuous tree on Nantucket Island.

5. Billings, W. D., S. A. Cain, and W. B. Drew.
   1937. **Winter key to the trees of eastern Tennessee.** Castanea 2: 29-44.
   Pitch pine is included in the key and is listed among trees occurring in Great Smoky Mountains National Park.

6. Blakeslee, A. F., and C. D. Jarvis.
   1911. **New England trees in winter.** Conn. Agr. Exp. Sta. Bull. 69. 576 pp., illus. Storrs.
   Contains a key to tree species and a description of each, including its range, especially in New England. Pitch pine occurs rarely in Litchfield County, but is common elsewhere in Connecticut.

7. Brooks, A. B.
   1920. **West Virginia trees.** W. Va. Agr. Exp. Sta. Bull. 175. 242 pp., illus.
   Contains a key to and description of tree species in West Virginia. Pitch pine occurs in 27 West Virginia counties, mostly on dry sandy soils of hillsides.

8. Brown, H. P.
   1921. **Trees of New York State, native and naturalized.** N. Y. State Coll. Forestry Tech. Pub. 15. 433 pp., illus.
   Briefly describes the habit, leaves, flowers, fruit, bark, habitat,

range, and use of pitch pine. Contains leaf, fruit, and twig keys to the New York species.

9. Burnham, Stewart H.
1913. **The flora of the sand barrens of southern Staten Island.** Torreya 13: 249-255.
Between Rossville and Kreischerville, Staten Island, N. Y., pitch pine occurs in sandy wastes, along with blackjack, post, and black oaks. Other associated plants are mentioned.

10. Carr, Lloyd G.
1940. **Further notes on coastal flora elements in the bogs of Augusta County, Virginia.** Rhodora 42: 86-93.
Pitch pine occurs in Magnolia Swamp.

11. Chittenden, Alfred K.
1905. **Forest conditions of northern New Hampshire.** U. S. Dep. Agr. Bur. Forestry Bull. 55. 100 pp., illus.
Pitch pine occurs chiefly on sandy soils in the Saco watershed, especially near Silver and Ossipee Lakes. Most pitch pine stands have been burned repeatedly, and trees are short and stunted.

12. Core, Earl L.
1950. **Notes on the plant geography of West Virginia.** Castanea 15: 62-79, illus.
Pitch pine occupies large areas in the Appalachians on dry ridges, flats, and slopes, often in pure stands, and especially on old fields. Pitch pine occurs in 28 counties—in the shale barrens and in the scrub oak, chestnut oak, scarlet oak-black oak, shortleaf pine-scrub pine, and white pine-chestnut oak-chestnut types.

13. Critchfield, William B., and Elbert L. Little, Jr.
1965. **Geographic distribution of the pines of the world.** U. S. Dep. Agr. Misc. Pub. 991. 97 pp., illus.
Briefly describes and illustrates the range of pitch pine. Pitch pine is thought to cross naturally with shortleaf and loblolly pines and to intergrade in Delaware and southern New Jersey with pond pine.

14. Dayton, William A.
1953. **Geography of commercially important United States trees.** J. Forestry 51: 276-279.
Pitch pine is merely listed as a species occurring only east of the Mississippi River.

15. Deam, Charles C.
1931. **Trees of Indiana.** Ind. Dep. Conserv. Pub. 13. 326 pp., illus.
Though pitch pine had been reported in Clark County, it is not native.

16. Deane, Walter.
1909. **Notes from Shelburne, New Hampshire.** Rhodora 11: 21-22.

Pitch pine occurs in limited numbers in Coos County, the largest tree being 60 feet tall. (See also Rhodora 12: 99.)

17. Dutlinger, F. H.
1923. **The Sproul State Forest.** Forest Leaves 19: 24-26.
Pitch pine formed the original stands at higher elevations in the Sproul Forest of Clinton and Centre Counties, Pa.

18. Eggleston, W. W., George L. Kirk, and J. G. Underwood.
1915. **Flora of Vermont. List of ferns and seed plants growing without cultivation.** Vt. Agr. Exp. Sta. Bull. 187: 139-258.
Pitch pine is common on sandy soil in the northern Champlain Valley and in the Connecticut Valley north to Wells River.

19. Ferguson, William C.
1925. **Ferns and flowering plants of the Hempstead Plains, Long Island, New York.** Torreya 25: 109-113.
Pitch pine is common south of Hicksville, near the edge of the Plains.

20. Fernald, M. L.
1901. **Notes on some trees and shrubs of western Cheshire County, New Hampshire.** Rhodora 3: 232-236.
Pitch pine occurs on the Drewsville sand plain and on lower slopes of Fall Mountain to an elevation of 1,100 feet.

21. Fernald, M. L.
1919. **Lithological factors limiting the ranges of *Pinus banksiana* and *Thuja occidentalis*.** Rhodora 21: 41-67, illus.
The range of pitch pine in New England is briefly discussed.

22. Fogg, John M., Jr.
1930. **The flora of the Elizabeth Islands, Massachusetts.** Rhodora 32: 147-161, 226-258.
Pitch pine occurs occasionally, as at the east end of Naushon Island.

23. Freer, Ruskin S.
1950. **A preliminary checklist of plants of the central Virginia Blue Ridge.** Castanea 15: 1-37.
Pitch pine is listed as occurring in Bedford, Botetourt, Amherst, Rockbridge, Nelson, and Augusta Counties.

24. Graves, Arthur H.
1910. **Woody plants of Brooklin, Maine.** Rhodora 12: 173-184, illus.
In Brooklin (near Mt. Desert Island) pitch pine is rather rare, but is locally abundant in one tract.

25. Graves, C. B., *et al.* (Committee of Conn. Bot. Soc.).
1910. **Catalogue of the flowering plants and ferns of Connecticut.** Conn. Geol. and Natur. Hist. Surv. Bull. 14. 569 pp.
Pitch pine is rare in Litchfield County, but common elsewhere on sandy soils.

26. Griggs, Robert F.

1914. **Observations on the behavior of some species at the edges of their ranges.** Torrey Bot. Club Bull. 41: 25-49, illus.

On sandstone soils in Fairfield County, Ohio, pitch pine is common, fruits abundantly, and has many seedlings although it is at the edge of its range.

27. Hanmer, Charles C.

1940. **Plants of Fishers Island.** Torreya 40: 65-81.

A few old pitch pines occur on Fishers Island, N. Y.

28. Harper, Arthur R.

1951. **The conifers of Ohio.** Ohio Conserv. Bull. 15(3): 8-9, 28-29, illus.

Pitch pine occurs in almost every county of southeastern Ohio, with colonies as far north as Columbiana, Jefferson, Belmont, Guernsey, and Licking Counties.

29. Harper, Roland M.

1908. **The pine-barrens of Babylon and Islip, Long Island.** Torreya 8: 1-9, illus.

The Pine Barrens of Long Island, N. Y., are mostly in the southern half of Suffolk County, but extend a few miles into Nassau County —with patches west to near Hicksville. Plants associated with pitch pine are listed for both upland and swamp sites.

30. Harper, Roland M.

1914. **The coniferous forests of eastern North America.** Pop. Sci. Mo. 84: 338-361, illus.

Although pitch pine occurs from New Brunswick west to Ohio and south to northern Georgia, extensive stands are limited to southeastern Massachusetts, eastern Long Island, and southern New Jersey—usually on sites of little value for agriculture.

31. Harper, Roland M.

1919. **A forest reconnaissance of the Delaware Peninsula.** J. Forestry 17: 546-555, illus.

Pitch pine, which is rare elsewhere on the Peninsula, predominates in the coastal strip toward Cape Henlopen. This species is occasional in a Choptank zone, frequent in a Pocomoke zone.

32. Harper, Roland M.

1921. **Cape Cod vegetation.** Torreya 21: 91-98, illus.

On Cape Cod, Mass., pitch pine is more abundant than all other trees combined. Associated species are listed.

33. Harshberger, John W.

1910. **The vegetation of the Navesink Highlands.** Torreya 10: 1-10, illus.

In the Navesink Highlands on the northeastern Coastal Plain of New Jersey, pitch pine occurs occasionally on summits and slopes in predominantly deciduous forests.

34. Harshberger, John W.

1911. **Phytogeographic survey of North America.** 790 pp., illus. Wilhelm Englemann, Leipzig; G. E. Stechert & Co., New York.

Occurrence of pitch pine and associated plants is mentioned in Kittatinny Mountains of northern New Jersey, the Pennsylvania Poconos, New Jersey dunes, New England islands, New England hill tops and sand plains, Long Island, New Jersey Pine Barrens, Maryland and Virginia, southeastern Pennsylvania, Pennsylvania mountains, southern Appalachians, lake region of New York, and Ohio.

35. Hawes, Austin F.

1923. **New England forests in retrospect.** J. Forestry 21: 209-224.

Pitch pine forests occurred on drier soils and were boxed by early settlers for tar and turpentine. Lack of underbrush in coastal forests was due to fires set by Indians.

36. Hill, Albert F.

1914. **Notes on the flora of the Penobscot Bay Region, Maine.** Rhodora 16: 189-192.

Pitch pine occurs on Mount Desert, Mount Champlain at Isle au Haut, and at Brooklin.

37. Hitchcock, A. S., and Paul C. Standley.

1919. **Flora of the District of Columbia and vicinity.** U. S. Nat. Mus. Contrib. U. S. Nat. Herb. 21: 13-329, illus.

Pitch pine occurs on sandy soil, scattered among Virginia pines.

38. Hollick, Arthur.

1902. **Geological and botanical notes: Cape Cod and Chappaquidick Island, Mass.** N. Y. Bot. Gard. Bull. 2: 381-407, illus.

Most trees near Provincetown are pitch pine and oaks. Pitch pine has been planted or seeded to stabilize dunes.

39. Hollick, Arthur.

1924. ***Pinus rigida,* Eastern pitch pine.** Addisonia 9: 45-46, illus.

Briefly describes the range, distinguishing characteristics, and wood of pitch pine.

40. House, Homer Doliver.

1910. **The vegetation of Lookingglass Mountain.** Torreya 10: 29-34, illus.

Pitch pine occurs along the backbone of Lookingglass Mountain and on adjacent dry ridges, and is common in the adjacent region of Transylvania County, N. C. Associated plant species are mentioned.

41. House, Homer D.

1924. **Annotated list of the ferns and flowering plants of New York State.** N. Y. State Mus. Bull. 254. 759 pp.

Pitch pine is generally distributed throughout the State below 1,500 feet altitude on dry rocky or sandy soil. Pitch pine is very common on Long Island and Staten Island, on hills up the Hudson Valley, on sand plains between Albany and Schenectady, and west of Lake Champlain.

42. Hyland, Fay.
1946. **The conifers of Maine.** Maine Ext. Bull. 345. 20 pp., illus.

Contains a key to native coniferous species and a description of each, including appearance, bark, leaves, fruit, and occurrence. Pitch pine is found chiefly in barrens of southern Maine and on sandy soil or rocks northeastward along the coast to Hancock, Waldo, Kennebec, and Oxford Counties.

43. Hyland, Fay, and Ferdinand H. Steinmetz.
1944. **The woody plants of Maine, their occurrence and distribution.** Univ. Maine Stud. Second Ser. 59. 72 pp., illus.

Pitch pine is frequent and locally abundant but is sporadic northeastward. It is found throughout Maine on sandy soils or rocks south of Latitude 44°30′N. except in Waldo County.

44. Illick, Joseph S.
1926. **Common trees of New Jersey.** 107 pp., illus. Amer. Tree Assoc., Wash., D. C.

Gives distinguishing characteristics of various species, including pitch pine. Briefly describes its distribution in New Jersey.

45. Illick, Joseph S.
1928. **Pennsylvania trees.** Ed. 5, Pa. Dep. Forests and Waters Bull. 11. 237 pp., illus.

Keys to and descriptions of each species. The chestnut-rock (chestnut) oak-pitch pine type is widely distributed on mountain slopes in eastern, southern, south-central, and north-central Pennsylvania; and pitch pine is also a principal member of the scrub oak type in south-central and northeastern Pennsylvania. Pitch pine is rare in southeastern and southwestern Pennsylvania, but forms excellent pure stands in Franklin, Centre, Huntingdon, and Pike Counties.

46. Jones, Herbert L.
1892. **Catalogue of the phanerogams and ferns of Licking County, Ohio.** Denison Univ. Sci. Lab. Bull. 7: 1-103, illus.

Pitch pine is listed as rare on dry, rocky hillsides.

47. Kearney, Thomas H., Jr.
1897. **The pine barren flora in the east Tennessee mountains.** Plant World 1: 33-35.

Pitch pine occurs on sandy flats along French Broad River in Cocke County, Tennessee.

48. Keller, Ida A., and Stewardson Brown.
1905. **Handbook of the flora of Philadelphia and vicinity.** 360 pp. Phila. Bot. Club, Phila.

Localities are cited for pitch pine in seven counties of Pennsylvania and New Castle County, Delaware.

49. King, Wilbur L.
1912. **The flora of Northampton County, Pennsylvania.** Torreya 12: 97-107, illus.
Pitch pine occurs on dry, sandy, or rocky soil in the county.

50. Knoblock, Irving William.
1935. **Some recent observations on and additions to the flora of western New York.** Torreya 35: 7-10.
Pitch pine occurred sparingly along the Allegany River, and some seedlings of this species have been planted in Allegany State Park.

51. Knowlton, C. H.
1900. **On the flora of Chesterville, Maine.** Rhodora 2: 123-124.
Pitch pine is the common pine on a large sand plain in Franklin County.

52. Knowlton, C. H., J. A. Cushman, Walter Deane, and A. K. Harrison.
1908. **Reports on the flora of the Boston District—II.** Rhodora 10: 59-64.
Pitch pine is abundant on dry soils.

53. Latham, Roy.
1934. **Flora of the State Park, Orient, Long Island, N. Y.** Torreya 34: 139-149.
Pitch pine is common on ridges of sand and gravel. Associated species are mentioned.

54. Littlefield, E. W.
1928. **An uncommon association of pines in northern New York.** Rhodora 30: 129-131.
Pitch pine occurs on both sides of Lake Champlain, and is abundant in Ausable Valley to Ausable Forks. Near Clintonville, N. Y., one area contained stems of pitch, jack, red, and white pines.

55. Lyford, Charles A., and Louis Margolin.
1906. **Forest conditions in southern New Hampshire.** N. H. Forestry Comn. 1905-06 Rep.: 161-276, illus.
Pitch pine and scrub oak occupy areas northeast of Lake Winnipesaukee; these sites have coarse sand or gravel soils and have been burned repeatedly. Similar areas occur elsewhere.

56. Lyon, Charles J., and James W. Goldthwait.
1934. **An attempt to cross-date trees in drowned forests.** Geogr. Rev. 24: 605-614, illus.
Pitch pine occurs at Scarboro, near Portland, Maine; and pitch pine stumps have been found there under marsh and at Provincetown, Mass., under sand.

57. McAtee, W. L.

1916. **Plants collected on Matinicus Island, Maine, in late fall, 1915.** Rhodora 18: 29-45.

On Matinicus Island (18 miles from Rockland) numerous pitch pines grow on a rocky hill and on Northeast Point. Many are badly deformed, and others have been killed by the wind (salt spray?).

58. McCauley, O.D.

1951. **The woody plants of Coopers Rock State Forest.** Castanea 16: 49-63.

Pitch pines occurs along Quarry Run on the drier sites in Monongalia County, West Virginia.

59. McCormick, Jack, and John W. Andresen.

1963. **The role of *Pinus virginiana* Mill. in the vegetation of southern New Jersey.** N. J. Natur. News 18: 27-38, illus.

Map shows boundaries of pitch pine barrens, oak-pine fringe, and Virginia pine areas in southern New Jersey. Pitch pine covered 9 percent of the ground in a 67-year-old Virginia pine stand on formerly tilled land in Cumberland County.

60. McVaugh, Rogers.

1935. **Recent changes in the composition of a local flora.** Torrey Bot. Club Bull. 62: 479-489.

Pitch pine occurs in dry woods near Kinderhook, Columbia County, New York.

61. Millspaugh, C. F.

1913. **The living flora of West Virginia.** W. Va. Geol. Surv. V (A): 1-389, illus.

Pitch pine occurs in six counties.

62. Morton, B. R., and R. G. Lewis.

1917. **Native trees of Canada.** Canada Dep. Interior Forestry Br. Bull. 61. 233 pp., illus.

Pitch pine is usually about 30 feet tall and 6 to 8 inches in diameter. Brief descriptions of form, bark, twigs, leaves, and cones are given. Pitch pine barely extends into Canada, being found in New Brunswick, Quebec, and Ontario (at Thousand Islands).

63. Morton, B. R., R. G. Lewis, G. A. Mulloy, and G. C. Cunningham.

1963. **Native trees of Canada.** Canada Dep. Forestry Bull. 61. 6th ed., 291 pp., illus.

Pitch pine is found on Thousand Islands and adjacent mainland in Ontario, in Chateauguay County, Quebec, and reportedly in New Brunswick.

64. Munns, E. N.

1938. **The distribution of important forest trees of the United States.** U. S. Dep. Agr. Misc. Pub. 287. 176 pp., illus.

A map shows botanical distribution of pitch pine as known at that time.

65. Murrill, William Alphonso.
1920. **An excursion to Mountain Lake, Virginia.** Torreya 20: 116-119.
Pitch pine occurs on Brush Mountain near Blacksburg.

66. Newberry, J. S.
1860. **Catalogue of the flowering plants and ferns of Ohio.** Ohio State Board Agr. 14th Annu. Rep. (1859): 235-273.
Pitch pine is listed from central and southern Ohio.

67. Nichols, George E.
1920. **The vegetation of Connecticut. VI. The plant associations of eroding areas along the seacoast.** Torrey Bot. Club Bull. 47: 89-117, illus.
On many rocky islands pitch pines predominates.

68. Ogden, E. S., F. H. Steinmetz, and F. Hyland.
1948. **Check-list of the vascular plants of Maine.** Josselyn Bot. Soc. Bull. 8. 70 pp., illus.
Pitch pine occurs in 11 of the 16 counties of Maine.

69. Ohmann, Lewis F., and Murray F. Buell.
1968. **Forest vegetation of the New Jersey Highlands.** Torrey Bot. Club Bull. 95: 287-298.
Pitch pine occurs to a limited extent, mostly at high elevations and on sandy soils.

70. Pepoon, H. S.
1927. **An annotated flora of the Chicago Area.** Chicago Acad. Sci. Natur. Hist. Surv. Bull. 8. 554 pp., illus.
Pitch pine is naturalized on sand flats north of Waukegan, Ill.

71. Pinchot, Gifford, and W. W. Ashe.
1897. **Timber trees and forests of North Carolina.** N. C. Geol. Surv. Bull. 6. 227 pp., illus.
Pitch pine occurs in the western part of the Piedmont and in the mountains south of French Broad River.

72. Radford, Albert E., Harry E. Ahles, and C. Ritchie Bell.
1968. **Manual of the vascular flora of the Carolinas.** 1183 pp., illus. Univ. N. C. Press, Chapel Hill.
Pitch pine occurs on poor soils in low mountains, but rarely in the Piedmont. Dot map shows that pitch pine grows in 24 North Carolina counties and 4 South Carolina counties.

73. Rigg, G. B., and P. D. Strausbaugh.
1949. **Some stages in the development of sphagnum bogs in West Virginia.** Castanea 14: 129-148, illus.
Pitch pine occurs in Big Droop Bog, Pocahontas County, at 3,060 feet elevation—along with red spruce, hemlock, white pine, red maple, and blackgum.

74. Rouleau, Ernest.

1955. ***Pinus rigida*** **Miller in Quebec.** Rhodora 57: 299.

A natural stand of pitch pine, growing with some white and red pines, covers about a square mile at Cairnside in Chateauquay County.

75. Schaffner, John H.

1921. **Additions to the catalog of Ohio vascular plants for 1920.** Ohio J. Sci. 21: 128-135.

Pitch pine occurs near Marietta, Washington County.

76. Selby, A. D., and J. W. T. Duvel.

1899. **Sources of the Ohio flora.** Columbus Hort. Soc. Proc. 14: 35-39.

Pitch pine is listed as a typical species in the unglaciated southeastern part of Ohio and the glaciated hills of southwestern Ohio.

77. Shanklin, John F.

1954. **Natural areas.** J. Forestry 52: 375-383.

Two natural areas of the pitch pine type are in George Washington National Forest, Augusta and Rockingham Counties, Virginia.

78. Small, John K., and Anna Murray Vail.

1893. **Report of the botanical exploration of southwestern Virginia during the season of 1892.** Torrey Bot. Club. Mem. 4: 93-201, illus.

Pitch pine was found on Peak Mountain at 2,200 feet elevation and on Round Top Mountain at 2,600 feet.

79. Smith, L. B., *et al.*

1933. **Reports on the flora of Massachusetts—II.** Rhodora 35: 351-359.

Pitch pine is common on sandy soil in southeastern Massachusetts, frequent elsewhere in eastern Massachusetts, only occasional westward.

80. Stone, Witmer.

1911. **The plants of southern New Jersey with especial reference to the flora of the Pine Barrens and the geographic distribution of the species.** N. J. State Mus. Annu. Rep. 1910: 21-828, illus.

Contains keys for identification and brief description of geographic distribution. Pitch pine, though occurring occasionally in the North and Middle Districts, is called the common pine of the Pine Barrens.

81. Svenson, H. K.

1923. **Plant notes from Squam Lake, New Hampshire.** Rhodora 25: 183-185.

Pitch pine occurs on southern slopes of Rattlesnake Mt.

82. Taber, William S.

1960. **Delaware trees: a guide to the identification of the**

native tree species. Del. State Forestry Dep Ed. 2, 254 pp., illus.

Describes tree form, leaves, bark, buds, flowers, fruit, seed, wood, distribution, and habitat of pitch pine. In Delaware pitch pine is present in all counties, but chiefly in Sussex County.

83. Tatnal, Robert R.

1946. **Flora of Delaware and the Eastern Shore.** An annotated list of the ferns and flowering plants of the peninsula of Delaware, Maryland and Virginia. 313 pp., illus. Del. Soc. Natur. Hist. Wilmington.

Pitch pine occurs usually as scattered trees in dry woods, swamps, and coastal sand dunes—infrequent in New Castle County but more common in Sussex County and southward.

84. Taylor, Norman.

1915. **Flora of the vicinity of New York, a contribution to plant geography.** N. Y. Bot. Gard. Mem. 5:1-683, illus.

Pitch pine is the predominant tree in the New Jersey Pine Barrens and is common on Long Island. It is found throughout Connecticut, New Jersey, southeastern New York, and eastern Pennsylvania, decreasing northward in all these states.

85. Tidestrom, Ivar.

1913. **Notes on the flora of Maryland and Virginia—I.** Rhodora 15: 101-106.

Pitch pine is a northern tree, not found on the Virginia Coastal Plain. It is common in the mountains, as at Cumberland, Md., and Covington, Va., where it grows with table-mountain pine and white pine. In the Coastal Plain north of Lewes, Del., and in the Piedmont, it grows with Virginia pine and sometimes with loblolly pine.

86. Transeau, E. N., and P. E. Williams.

1929. **Distribution maps of certain plants in Ohio.** Ohio Biol. Surv. Bull. 20: 179-217, illus.

Distribution of pitch pine in Ohio and neighboring portions of Pennsylvania, West Virginia, and Kentucky, is shown on county outline map.

87. Twitchell, D. G., and M. B. Harris.

1925. **Some results of the first season's work at the University of Maine's summer biological station at Mt. Desert Island (1924). Part II. Pitch pine region, Pickett Mountain.** Maine Natur. 5: 11-23, illus.

Pitch pine occurs on the southern slope in the scanty soil of ledges, but is stunted. Associated plants and fauna are listed or briefly described.

88. Vermeule, C. C.

1900. **The forests of New Jersey.** N.J. State Geol. Annu. Rep. 1899: 13-101, 137-172, illus.

Pitch pine, usually accompanied by scrub oak, occurs on rocky mountain crests (Kittatinny, Bearfort, Green Pond, and Copperas) in northern New Jersey and on the highest sandy ground in the Pine Region of southern New Jersey. Heights, diameters, and yields of some pitch pine stands are given. Especially along the edges of the Pine Region, oaks replace pine after latter is cut; but in abandoned clearings pure pine stands develop. Some large fires in the Pine Region are described.

89. Weatherby, C. A., C. H. Knowlton, and R. C. Bean.
1926. **Fifth report of Committee on Floral Areas., Preliminary lists of New England plants—XXX.** Rhodora 28: 43-46.

Pitch pine occurs chiefly in the three southern states, but also at low altitudes in Champlain, Connecticut, Androscoggin, and lower Kennebec valleys, near Lake Ossipee, N. H., and along the Maine coast to Mt. Desert Island.

90. Wiegand, Karl M., and Arthur J. Eames.
1925. **The flora of the Cayuga Lake Basin, New York. Vascular plants.** Cornell Univ. Agr. Exp. Sta. Mem. 92. 491 pp., illus.

Pitch pine is frequent in the Basin on scattered ravine crests, on high hills south of Ithaca, along lake cliffs, and on sands north of the Lake.

Resource Statistics

91. Armstrong, George R., and John C. Bjorkbom.
1956. **The timber resources of New York.** USDA Forest Serv. NE Forest Exp. Sta., 37 pp., illus. Upper Darby, Pa.

The area in pitch pine and pitch pine-oak types was reported to be 161,000 acres; and as a major type pitch pine is restricted mostly to a portion of Long Island.

92. Clepper, Henry E.
1936. **The Mont Alto State Forest.** J. Forestry 34: 30-35. 522.

In 1934, 87 percent of the 23,537 acres of the Forest (in Franklin and Adams Counties, Pa.) was in the mixed oak-pitch pine type; 6 percent of the stems 4 inches and larger in diameter (b.h.) were pitch pines.

93. Conway, Emmett A.
1950. **Timber survey of the Hocking State Forest.** Ohio Agr. Exp. Sta. Res. Circ. 3. 29 pp., illus.

Pitch pine is very aggressive on farmland abandoned since 1900 in Hocking County, Ohio. Tabular data indicate density, volume, mean diameter, cull percentage, and growth rate. Pitch pine is sixth among species in board-foot volume.

94. Cook, H. O.

1929. **A forest survey of Massachusetts.** J. Forestry 27: 518-522.

The pitch pine-oak type made up 8 percent of the forest land, but some pitch pine areas were also included in the 2 percent of "other softwoods". Only about 10 percent of the type had stands with trees 6 inches and larger in diameter. Bear oak prevails among oaks in frequently burned areas, tree oak species elsewhere.

95. Craig, Ronald B.

1949. **Virginia forest resources and industries.** U. S. Dep. Agr. Misc. Pub. 681. 64 pp., illus.

The shortleaf-pitch pine type covers 573,900 acres of commercial forest land in the mountains of western Virginia, occurring as bands on the eastern slopes. A type map indicates distribution. The volume of pitch pine exceeds that of shortleaf pine.

96. Ferguson, Roland H.

1958. **The timber resources of Pennsylvania.** USDA Forest Serv., NE. Forest Exp. Sta. 46 pp., illus. Upper Darby, Pa.

The pitch-Virginia pine type covers 210,000 acres of commercial forest land, the yellow pine-oak type 153,000 acres, and the oak-pitch pine type 81,000 acres. Pitch pine sawtimber and growing-stock volumes are about three times those of Virginia pine.

97. Ferguson, Roland H.

1964. **The timber resources of West Virginia.** USDA Forest Serv. Resource Bull. NE-2. 123 pp., illus. NE. Forest Exp. Sta., Upper Darby, Pa.

Growing-stock volume in pitch and Virginia pines on commercial forest land was 234 million cubic feet. Map shows general location of main forest types, including shortleaf-pitch pine.

98. Ferguson, Roland H.

1967. **The timber resources of Maryland.** USDA Forest Serv. Resource Bull. NE-7. 93 pp., illus. NE. Forest Exp. Sta., Upper Darby, Pa.

The southern pine type covers 600,000 acres, and oak-pine type 299,000 acres, but only small amounts of pitch pine are included therein.

99. Ferguson, Roland H.

1968. **The timber resources of Pennsylvania.** USDA Forest Serv. Resource Bull. NE-8. 147 pp., illus. NE. Forest Exp. Sta., Upper Darby, Pa.

The Virginia-pitch pine type covers 208,000 acres of commercial forest land in Pennsylvania, the oak-pine type 135,000 acres. Volumes in other yellow pines (presumably mostly pitch pine) are far more than in Virginia pine: in sawtimber volume five times that in Virginia pine.

100. Ferguson, Roland H., and Milford C. Howard.
1956. **The timber resource in Massachusetts.** USDA Forest Serv. NE. Forest Exp. Sta. 45 pp., illus. Upper Darby, Pa.

The pitch pine type covers 114,000 acres, pitch pine-oak type 51,000 acres, and oak-pitch pine 46,000 acres of commercial forest land. Volumes include 36 million board feet of pitch pine sawtimber and 47 million cubic feet of pitch pine growing stock. As a major type, pitch pine occurs chiefly in Barnstable and Plymouth Counties.

101. Ferguson, Roland H., and Franklin R. Longwood.
1960. **The timber resources of Maine.** USDA Forest Serv., NE. Forest Exp. Sta., 75 pp., illus. Upper Darby, Pa.

The pitch pine and jack pine types cover 15,000 acres in Maine.

102. Ferguson, Roland H., and John R. McGuire.
1957. **The timber resources of Rhode Island.** USDA Forest Serv., NE. Forest Exp. Sta. 38 pp., illus. Upper Darby, Pa.

The oak-pitch pine type covers 3,000 acres.

103. Northeastern Forest Experiment Station.
1954. **Forest statistics for New York Forest District No. 13.** USDA Forest Serv. NE. Forest Exp. Sta. 19 pp. Upper Darby, Pa.

In Orange, Rockland, Sullivan, and Ulster Counties there are 14.4 million cubic feet of pitch pine growing stock or 53.2 million board feet of sawtimber. Pitch pine types cover about 3 percent of the commercial forest land.

104. Northeastern Forest Experiment Station.
1954. **Forest statistics for New York District No. 15.** USDA Forest Serv. NE. Forest Exp. Sta. 19 pp. Upper Darby, Pa.

In 1950 the pitch pine type covered 88,200 acres of commercial forest land on Long Island. Pitch pine volumes were 44.6 million board feet of sawtimber or 21.9 million cubic feet of growing stock.

105. Northeastern Forest Experiment Station.
1955. **Forest statistics for New York.** USDA Forest Serv. NE. Forest Exp. Sta. 63 pp., illus. Upper Darby, Pa.

The pitch pine type, in which pitch pine forms 75 percent or more of the stand, covers 107,800 acres, or 1 percent of the commercial forest area of the State.

106. Northeastern Forest Experiment Station.
1955. **The timber resource in Maryland.** USDA Forest Serv. NE. Forest Exp. Sta. 41 pp., illus. Upper Darby, Pa.

Pitch pine-Virginia pine, pitch pine-Virginia pine-oak, and oak-pitch pine-Virginia pine forest types occupy 16 percent of the commercial forest land in Maryland. Pitch pine volumes are estimated as 85 million board feet of sawtimber, 37 million cubic feet of growing stock.

107. Webster, Henry H., and Carl H. Stoltenberg.

1958. **The timber resources of New Jersey.** USDA Forest Serv. NE. Forest Exp. Sta. 41 pp., illus. Upper Darby, Pa.

Pitch, shortleaf, and Virginia pine types cover 534,000 acres; hard pine-oak and oak-hard pine, 261,000 acres. Pitch pine sawtimber and growing-stock volumes are given as 222 million board feet and 132 million cubic feet.

BOTANICAL CHARACTERISTICS

Taxonomy

108. Allard, H. A.

1940. **A globose form of pitch pine *(Pinus rigida)* in Virginia.** Rhodora 42: 308.

A technical description of a new form, *globosa,* based on a single tree near Hopewell Gap, Fauquier County. The tree was 7.5 feet tall, 6.5 inches in diameter at base, and had a crown spread of 12 feet.

109. Anonymous. (G. H. Collingwood?)

1936. **Pitch pine. *Pinus rigida* Miller.** Amer. Forests 42: 224-225, illus.

Briefly describes the range, species characteristics (including leaves, flowers, cones, sprouts), wood, and site requirements. Pitch pine seed is mentioned as a food source for squirrels, quail, and small birds.

110. Best, G. N.

1890. **A preliminary study of the seed-wings of the Abietineae.** Microscope 10(1): 1-6.

Briefly describes the cell structure of the seed wings in pitch pine, indicating differences from other species.

111. Clausen, Robert T.

1939. **Contributions to the flora of New Jersey.** Torreya 39: 125-133.

Range is not a basis for distinguishing pitch pine from pond pine, and the nature of the prickles on cone scales is too variable; so length of leaves is the best criterion. Specimens considered typical of pond pine were collected from three counties in southern New Jersey, and specimens intermediate between pitch and pond pines from two counties.

112. Duffield, J. W.

1952. **Relationships and species hybridization in the genus *Pinus.*** Silvae Genetica 1: 93-97.

Taxonomic arrangements in the sub-genus Diploxylon by Pilger and by Shaw were reviewed and revised on the basis of hybridization results and supplementary evidence from biochemistry, anatomy, and morphology. Pitch pine was placed in group XI, made up of pines of the southeastern United States.

113. Engelmann, George.
1886. **Revision of the genus *Pinus*, and description of *Pinus Elliottii*.** Acad. Sci. St. Louis Trans. 4: 161-190, illus.
Briefly describes cotyledonous, primary, and secondary leaves of pines; size of pollen grains, retention of cones, number of cotyledons, flower and needle structure of pitch pine. The author could not distinguish pitch and pond pines because of variability in each.

114. Everett, T. H.
1946. **Plant portraits.** Gard. Chron. Amer. 50: 14-15, illus.
A brief description of the distinguishing characteristics of pitch pine, its role, and wood uses.

115. Fiske, Jessie G.
1935. **Fruits and seeds of some common New Jersey trees.** N. J. Agr. Exp. Sta. Circ. 355. 52 pp., illus.
Contains a brief description of pitch pine flowers, fruit, and seed.

116. Gordon, George, and Robert Glendinning.
1858. **The Pinetum: being a synopsis of all the coniferous plants at present known, with descriptions, history, and synonymes, and comprising nearly one hundred new kinds.** 353 pp. Henry G. Bohn, London.
Synonyms listed for *Pinus rigida* are *P. taeda rigida* Aiton, *P. fraseri* Loddiges, *P. canadensis trifolia* DuHamel, and *P. loddigesii* Loudon. Leaves, branches, cones, and seeds of pitch pine are described, as well as its height and distribution.

117. Harger, E. B.
1899. ***Liquidambar* at Greenwich, Connecticut.** Rhodora 1: 130-131.
A pitch pine near Stamford had leaves 7 inches long.

118. Harlow, W. M.
1931. **The identification of the pines of the United States, native and introduced, by needle structure.** N. Y. State Coll. Forestry Tech. Pub. 32. 21 pp., illus.
A brief description of terms, then a key followed by plates and a brief description for each species. Length of pitch pine needles is listed as 7 to 14 cm., the number as three per fascicle; and the distribution of resin canals, nature of hypoderm, structure of endodermis, and number of fibrovascular bundles are described.

119. Illick, J. S.
1921. **The hard pines of the Northeast.** Amer. Forestry 27: 487-496, illus.
Keys to the pine species. Common names of pitch pine are listed; and some effects of fires, distinguishing characters of pitch pine, and its role in forestry are described briefly.

120. Kellerman, W. A.

1892. **Note on yellow pitch pine.** Bot. Gaz. 17: 280.

A form of pitch pine having thinner, scarcely furrowed, reddish-yellow bark and deeper yellow, more durable heartwood was found in Fairfield County, Ohio, and was named *P. rigida* var. *lutea* Kellerman.

121. Little, Elbert L., Jr.

1944. **Notes on nomenclature in Pinaceae.** Amer. J. Bot. 31: 587-596.

Includes discussion of scientific names and authorities for calling pond pine either a variety of pitch pine or a separate species.

122. Loudon, J. C.

1838. **Arboretum et fructicetum britannicum.** 8 vols. (vol. 4: 2239-2242, illus.) Published by author, London.

Gives synonyms of *Pinus rigida* and brief descriptions of leaves, buds, cones, seed, and wood—as well as a description of pitch pine distribution and sites. Mentions production of tar from pitch pines of northern states, other uses of the wood, and the planting of pitch pine in England before 1759.

123. Michaux, F. Andrew.

1819. **The North American sylva, or a description of the forest trees, of the United States, Canada and Nova Scotia.** Vol. 3, 286 pp., illus. C. D. 'Hautel, Paris.

A scientific description of pitch pine, and a brief description of its buds, leaves, aments, cones, bark, growth habits, and wood, as well as the distribution. Cones open on some trees the first autumn, but "on solitary stocks" remain closed for several years. Mentions occurrence of pitch pine near Brunswick, Maine, and Burlington, Vermont; on the ridges of the Alleghenies; and in southern New Jersey and Maryland. Pitch pine withstands flooding by sea-water and commonly grows on sandy soils. It reaches heights of 70 to 80 feet and diameters of 20 to 28 inches. Describes uses of wood, including the production of tar in New England, New Jersey, and the Allegheny Mountains (last for Ohio River shipbuilders).

124. Miller, Philip.

1768. ***Pinus. In* Gardener's Dictionary, Ed. 8.** London: printed for author.

Contains original, but exceedingly brief description of pitch pine in Latin and English.

125. Sargent, Charles Sprague.

1897. ***Pinus rigida.* Pitch pine. *In* The silva of North America, a description of the trees which grow naturally in North America exclusive of Mexico. Vol. 11, Coniferae (*Pinus*):** 115-118, illus. Houghton, Mifflin and Company, Boston and New York.

Cites authors dealing with the nomenclature of pitch pine, and gives detailed descriptions of leaves (including primary leaves of sprouts), bark, buds, form, flowers, cones, and seeds. Briefly describes the distribution of the species and the sites it inhabits; the wood and its uses; the production of turpentine and tar from pitch pine stands of New England and the Middle Atlantic States.

126. Sargent, Charles Sprague.

1933. **Manual of the trees of North America (exclusive of Mexico).** Ed. 2, 910 pp., illus. Houghton Mifflin Company, Boston and New York.

Leaves, flowers, fruit, seeds, bark, wood, tree form, and geographic distribution of pitch pine are described.

127. Shaw, George Russell.

1914. **The genus *Pinus*.** Arnold Arboretum Pub. 5. 96 pp., illus.

Describes genus characters for cotyledon, bud and branchlet, primary and secondary leaves, flowers, cones, seeds, wood and bark. For each species, including pitch pine, descriptions of shoots, leaves, cones, and range are given. Pitch pine cones are rarely serotinous, but the species is placed in the Insignes group.

Chemistry, Physiology, and Morphology (including radiation effects)

128. Abbe, Lucy B., and A. S. Crafts.

1939. **Phloem of white pine and other coniferous species.** Bot. Gaz. 100: 695-722, illus.

Phloem is described in detail, including changes associated with sieve-tube initiation, maturation, senility, and death. Pitch pine is mentioned as one of the species investigated.

129. [Avebury] Lubbock, Sir John.

1892. **A contribution to our knowledge of seedlings.** 2 vol., 608 + 646 pp., illus. Kegan Paul, Trench, Trubner & Co., London.

Pitch pine seedlings have four to six acicular cotyledons, which reach a length of 1.4 to 1.6 cm. The primary root tapers downward, unbranched for some time after germination. The hypocotyl is 8 to 18 mm. long, erect, glabrous, deep glaucous-green, and stained with red near base. Cotyledons and primary and secondary leaves are described.

130. Bailey, I. W., and W. W. Tupper.

1918. **Size variation in tracheary cells: I. A comparison between the secondary xylems of vascular cryptogams, gymnosperms, and angiosperms.** Amer. Acad. Arts and Sci. Proc. 54: 149-204, illus.

In pitch pine wood more than 60 rings from the pith, the maximum, minimum, and mean lengths of tracheids were 5.3, 3.2, and 4.0 mm.

131. Bean, W. J.

1909. ***Pinus rigida.*** Gardeners' Chron. 45: 178-179, illus.

Some of the planted pitch pines in England are described, as well as their leaves, buds, cones, and short twigs along boles. Planted trees have reached 75 feet in height and 11 feet in girth. Illustration shows clusters of cones on one tree.

132. Chang, Ying-Pe.

1954. **Bark structure of North American conifers.** U. S. Dep. Agr. Tech. Bull. 1095. 86 pp., illus.

Describes specific and generic characteristics, diagnostic features, and significance of bark structure, and gives an artificial key to families and genera. Pitch pine was one of the species studied, but no specific description of its bark is presented.

133. Hong, S. O.

1963. **The effect of some growth regulators upon the development of male gametophyte of pitch pine.** Korean Inst. Forest Genet. Res. Rep. 3: 57-60, illus.

To induce male sterility in pitch pine, gibberellin, 2,4-D, phosfon, and some other compounds were tried as sprays. 2,4-D was the most effective, but damaged trees.

134. Jackson, Robert Tracy.

1899. **Localized stages in development in plants and animals.** Boston Soc. Natur. Hist. Mem. 5: 89-153, illus.

Of 100 pitch pine seedlings, 55 had 5 cotyledons; the others had 4, 6, or 7 (1 seedling had 7). Gives detailed descriptions of cotyledons and primary and mature leaves, and mentions where these occur on seedlings and sprouts. Includes several drawings of pitch pine.

135. Mergen, François, and T. Strøm Johansen.

1963. **Effect of ionizing radiation on microsporogenesis in *Pinus rigida* Mill.** Radiat. Bot. 3: 321-331, illus.

Trees receiving 82 r/day and higher since November were unable to resume cell division in the spring. At 56 r/day meiosis occurred, but viable microspores were collected at no higher levels than 11 r/day. At even lower levels strobili length was adversely affected, and the proportion of cells with visible chromosome aberrations was increased. Pollen abortion increased as radiation was increased.

136. Mergen, François, and T. Strøm Johansen.

1964. **Effect of ionizing radiation on seed germination and seedling growth of *Pinus rigida* (Mill.).** Radiat. Bot. 4: 417-427, illus.

Pitch pine seeds in cones on the trees were exposed to gamma irradiation from 0.36 r/day to 840 r/day, with total exposures up to 22,700 r. Germination was not affected at rates up to 130 r/day and a total of 16,000 r. At 295 r/day germination was reduced after 8,000 r. At 6,000 to 8,000 r, root length was stimulated, and fresh weight increased, but overall growth was reduced above 8,000 r. Within 2 years differences in seedling height between irradiated and control seeds had disappeared.

137. Mergen, F., and G. R. Stairs.
1962. **Low level chronic gamma irradiation of a pitch pine-oak forest—its physiological and genetical effects on sexual reproduction.** Radiat. Bot. 2: 205-216, illus.

Stages in the development of normal pitch pine flowers are briefly described. With an increase in gamma radiation accumulated by trees, the cone length, seed germination, and height of resulting seedlings all declined. Under certain circumstances seed stored in cones could regenerate a pitch pine forest killed by radiation.

138. Mergen, François, and G. R. Stairs.
1963. **Cumulative radiation effects on sexual reproduction in pine and oak.** Forest Tree Impr. Comm. Pub. 22(1962 Forest Genet. Workshop Proc.): 79-87, illus.

Pitch pines severely damaged by low-level radiation did differentiate floral structures and produce viable seed, but flower phenology was retarded, pollen abortion increased and pollen germination decreased, morphological aberrations occurred, and resulting seedlings showed several abnormalities.

139. Mergen, François, and G. R. Stairs.
1963. **Progeny test from a pitch pine-oak forest damaged by low level chronic gamma radiation.** NE. Forest Tree Impr. Conf. Proc. 10: 3-8, illus.

Decrease in germination of pitch pine seed was not associated with radiation accumulated by seed lot, but with total dose received by the parent tree before and during seed formation. At the cotyledon stage seedlings from irradiated seed were significantly shorter. Pitch pine was more sensitive than associated oaks.

140. Meyer, Bernard S.
1928. **Seasonal variations in the physical and chemical properties of the leaves of the pitch pine, with especial reference to cold resistance.** Amer. J. Bot. 15: 449-472, illus.

Total water content of mature pitch pine leaves does not vary markedly with season, but is lowest in late spring. During summer months leaves are easily killed by freezing in an ice-salt bath, but in winter are not killed—possibly because of increase in colloidal gels that increase the proportion of bound water. Sugar content of leaves is high in winter, and this may also be important in cold resistance.

141. Meyer, Bernard S.
1932. **Further studies on cold resistance in evergreens, with special reference to the possible role of bound water.** Bot. Gaz. 94: 297-321, illus.

Pitch pine branches collected in winter have leaves resistant to cold even if first kept at greenhouse temperatures for 3 weeks. Foliage of summer-collected branches is very susceptible. Summer foliage has greater amounts of bound and free water, but there is no evidence that bound water accounts for pitch pine's cold resistance.

142. Mirov, N. T.

1951. **Composition of gum turpentines of pines: a report on *Pinus echinata, P. rigida,* and *P. ponderosa* from Utah.** Amer. Pharm. Assoc. J. Sci. Ed. 40: 410-413.

Similar information as in 1961 paper.

143. Mirov, N. T.

1961. **Composition of gum turpentines of pines.** U. S. Dep. Agr. Tech. Bull. 1239. 158 pp., illus.

The turpentine yield of pitch pine oleoresin, and the physical properties and chemical composition of turpentine, are described for one sample collected near Asheville, N. C.

144. Murrill, W. A.

1901. **The generative divisions in Gymnosperms.** Torreya 1: 131-132.

A brief description of the division of the pitch pine pollen ovule into two cells, one taking an active part in fertilization and the smaller one becoming a total loss.

145. Parr, Thaddeus.

1943. **Voltage gradients in trees as an indicator of susceptibility to insect attack.** J. Forestry 41: 417-421, illus.

Millivoltage data for potted pitch pines 3 to 5 feet tall. Negative values were obtained in winter; positive values of 7 to 20 mv. were obtained during the growing season.

146. Shaw, George Russell.

1907. **Characters of *Pinus:* the lateral cone.** Bot. Gaz. 43: 205-209, illus.

In pines having uninodal shoots, the position of the pistillate flower is subterminal; but in multinodal shoots, such as pitch pine may have, the position may be subterminal or lateral or both.

147. Smith, Richard H.

1967. **Monoterpene composition of pine species and hybrids.** USDA Forest Serv. Res. Note PSW-135. 14 pp. Pacific Southwest Forest & Range Exp. Sta., Berkeley, Calif.

The hybrid *rigida* X *taeda* had a composition generally intermediate between the two parents.

148. Smith, William H.

1969. **Release of organic materials from the roots of tree seedlings.** Forest Sci. 15: 138-143, illus.

Root exudates of 18-day-old seedlings of pitch pine, three other pines, and black locust were analyzed by thin-layer chromatography. Of the four pines, pitch pine released the lowest amount of soluble compounds. Compounds released by pitch pine included glucose and sucrose, eight amino acids or amides, and three organic acids.

149. Spalt, Karl W., and William E. Reifsnyder.
1962. **Bark characteristics and fire resistance: a literature survey.** USDA Forest Serv. S. Forest Exp. Sta. Occas. Paper 193. 19 pp., illus. New Orleans, La.

Presents previously unpublished data obtained by P. W. Stickel on the ratio of outer bark to total bark for pitch pines 5, 10, and 50 years old and on moisture content of bark at different seasons (minimum in winter). Stickel concluded that fire resistance of pitch pine boles is due to the deep-seated location of the periderm from an early age—so that the cork layer is constantly being augmented by a great amount of phloem that assumes a cork-like character.

150. Sparrow, A. H., L. A. Schairer, and G. M. Woodwell.
1965. **Tolerance of *Pinus rigida* trees to a ten-year exposure to chronic gamma irradiation from cobalt-60.** Radiat. Bot. 5: 7-22, illus.

After 8 years of exposure, 50 percent of the trees were killed by rates of 3.1 r/day; after 10 years 20 percent were killed by rates as low as 2.5 r/day. None survived cumulative exposures above 13 kr. Radial increment and needle length were reduced—50 percent growth reduction at about 3 r/day. Number of mature seeds was reduced to about 10 percent of the control by average exposure of 3.5 r/day, and no cones formed above 7.4 kr cumulative exposure.

151. Sparrow, A. H., and G. M. Woodwell.
1962. **Prediction of the sensitivity of plants to chronic gamma irradiation.** Radiat. Bot. 2: 9-26, illus.

Both vegetative growth and the sexual reproductive process of pines seem highly susceptible to radiation, and pines are among the most sensitive plants known. Detectable effects were found on pitch pine at rates as low as 2 r/day over 9-year period. Reasons for sensitivity of pines are their large nuclear volume and the long period involved in sexual reproduction. *Gaylussacia baccata* is one of the most resistant of the associated species.

152. Stairs, G. R., and F. Mergen.
1964. **Potential uses of irradiated pollen in forest genetics.** NE. Forest Tree Impr. Conf. Proc. 11: 38-41.

As much as 70 percent of pitch pine pollen that had been exposed to radiation levels up to 30,000 r germinated, and 61 percent of the pollen that had been exposed to 300,000 r germinated after storage for 10 months in a refrigerated desiccator.

153. Tepper, Herbert B.
1963. **Leader growth of young pitch and shortleaf pines.** Forest Sci. 9: 344-353, illus.

Leader elongation often involves formation and elongation of several buds. Winter buds of pitch pine are often multinodal: the basal internode expands first, then the second, and later the third (if any)—and each achieves its peak growth after the one below it. As internodes elongate, terminal bud forms, but in pitch pine this only occasionally elongates as a summer shoot in the same season. Height growth may take 2½ to 4 months in New Jersey, but 90 percent occurs in about 65 days.

154. Williams, Allette L., and M. H. Bannister.
1962. **Composition of gum turpentines from twenty-two species of pines grown in New Zealand.** J. Pharm. Sci. 51(10): 970-975, illus.

Yield of turpentine from pitch pine in New Zealand was 17.8 percent. Its chemical composition is described.

155. Woodwell, G. M., and Lee N. Miller.
1963. **Chronic gamma radiation affects the distribution of radial increment in *Pinus rigida* stems.** Sci. 139: 222-223, illus.

Exposure to rates of 1 to 5 r/day for several years reduces radial increment throughout pitch pine stems, but especially near the base. Trees with large crowns showed little effect at low exposures except during drought years.

156. Woodwell, G. M., and A. L. Rebuck.
1967. **Effects of chronic gamma radiation on the structure and diversity of an oak-pine forest.** Ecol. Monogr. 37: 53-69.

Pitch pine was the most sensitive plant, and it was selectively killed over the largest area. It was eliminated from a devastated zone where all indigenous plants were killed, from a zone where *Carex* was the principal survivor, from a shrub zone where *Carex* and shrubs survived, and from an oak-forest zone where pines were killed. Factors affecting species survival are discussed.

157. Woodwell, G. M., and A. H. Sparrow.
1963. **Predicted and observed effects of chronic gamma radiation on a near-climax forest ecosystem.** Radiat. Bot. 3: 231-237, illus.

Shoot growth and mortality of pitch pine and five associated woody species that were subjected to radiation were compared with responses predicted on the basis of nuclear volume and chromosome number. Pitch pine and the other species were generally more sensitive than predicted.

158. Yim, K. B.
1963. **Karotype analysis of *Pinus rigida.*** Hereditas 49: 274-276, illus.

The haploid karotype of pitch pine has six chromosomes, each with secondary constriction. However, the author's data were not entirely consistent.

Races and Hybrids

159. Ahn, K. Y.

1963. **Studies on interspecific hybridization in the sub-genus Diploxylon of genus Pinus.** Korean Inst. Forest Genet. Res. Rep. 3: 29.

Controlled pollinations were made between *P. rigida* and *P. densiflora, P. elliottii, P. taeda, P. echinata,* or *P. radiata.* Much fertile hybrid seed was obtained by crossing *P. rigida* and *P. radiata,* but the cross between *P. rigida* and *P. taeda* was the most promising. Growth rate, cold hardiness, and some other characteristics were intermediate between parents.

160. Austin, Lloyd.

1929. **The Eddy Tree Breeding Station.** Madroño 1: 203-227, illus.

G. S. Perry reported a natural hybrid between pitch and shortleaf pines near Mt. Alto, Pa.

161. Hyun, S. K.

1962. **Improvement of pines through hybridization.** Int. Union Forest Res. Organ. Proc. 13th Congr. vol. 1, part 2, sect. 22, paper 11. 11 pp.

Presents data on growth of 3-year-old pitch-loblolly hybrids compared to pitch pine, and discusses the mass production of hybrids, source of pollen, and other breeding efforts for pitch pine hybrids in Korea.

162. Hyun, Sin Kyu.

1962. **Mass production of control-pollinated seed of conifers.** Fifth World Forestry Congr. Proc. 2: 787-791.

Similar to other articles on pitch-loblolly hybrids in Korea, but in somewhat more detail.

163. Hyun, Sin-kyu, and Kun-Yong Ahn.

1959. **Mass production of pitch-loblolly hybrid pine (X *Pinus rigitaeda*) seed.** Korean Inst. Forest Genet. Res. Rep. 1: 11-24, illus.

For 5 years 10- to 14-year-old pitch pine plantations have been used to mount 11,000 to 30,000 pollination bags. Pitch pine flowers were pollinated with loblolly pine pollen imported from U. S. A.; 20 seeds were obtained per cone from the crossing. Costs are given for different steps.

164. Hyun, Sin-kyu, and Kun-Yong Ahn.

1959. **Principal characteristics of X *Pinus rigitaeda.*** Korean Inst. Forest Genet. Res. Rep. 1: 35-50, illus.

Pitch-loblolly pine hybrids are intermediate between parent species in rapidity of germination, length and width of needle, length of needle sheath, needle color, and cold hardiness. In form and size of cones and seeds and the distribution of vascular bundles in the leaf, hybrids resemble pitch pine. Growth over 3 years is superior to that of pitch pine.

165. Hyun, Sin Kyu, Chung Suk Kim, and Suk Goo Lee.
1967. **A study on the variants of *Pinus rigida* X (*P. rigida* X *P. taeda*) appeared in the forest nursery.** Korean Inst. Forest Genet. Res. Rep. 5: 1-18, illus.

Backcross hybrids were classed into four types based on length and form of needles. These types differed in chromosome number, height growth, width and thickness of needles, number of resin canals in needles, stomata length, length and thickness of tracheids, and diameter and behavior of pollen grains.

166. Hyun, Sin Kyu, and Kun Hoe Koo.
1964. **Some characteristics of backcross hybrids of X *Pinus rigitaeda.*** Korea Min. Agr. and Forestry Office Rural Develop. 7(2): 63. (English summary only). (Also 1965. Korean Inst. Forest Genet. Res. Rep. 4: 11).

Backcrosses with loblolly pine outgrew crosses of F_1 hybrid and pitch pine, but the latter were distinctly more cold-hardy.

167. Hyun, Sin Kyu, Kun Hoe Koo, Sung Ho Hong, and Bo Sik Lee.
1967. **Some characteristics of X *Pinus rigida* • *radiata.*** Korean Inst. Forest Genet. Res. Rep. 5: 33-42, illus.

The hybrid has intermediate characteristics in form of cone, seed, and needle, and has shown good cold hardiness and better growth than pitch pine in South Korea.

168. Keng, Hsuan, and Elbert L. Little, Jr.
1961. **Needle characteristics of hybrid pines.** Silvae Genetica 10(5): 131-146, illus.

Lists the needle number and length, the number of cell layers in the hypodermis, and the number and position of resin canals for loblolly, pond, and pitch pines and for hybrids between each of the other two species and pitch pine.

169. Kim, Chung Suk, Suk Koo Lee, and Min Sup Chung.
1967. **Studies on artificial polyploid forest trees. IV. On some characteristics of induced polyploids of *Pinus rigida* Mill.** Korean Inst. Forest Genet. Res. Rep. 5: 19-31, illus.

The results of morphological and cytological investigations are described for three types of colchiploids obtained from treating pitch pine seeds with colchicine.

170. Koo, Kun Hoe, and Sung Ho Hong.
1967. **Tracheid length and compression strength of X *Pinus rigitaeda* and its backcross hybrid.** Korean Inst. Forest Genet. Res. Rep. 5: 85-90.

Tracheid length of the hybrid was about the same as that of loblolly pine, and longer than that of pitch pine. A backcross to pitch pine was intermediate between parents in some respects.

171. Little, Elbert L., Jr., and Francis I. Righter.
1965. **Botanical descriptions of forty artificial pine hybrids.** U. S. Dep. Agr. Tech. Bull. 1345. 47 pp., illus.

Botanical descriptions of artificial hybrids between pitch pine and shortleaf, loblolly, or pond pines, and brief descriptions of their growth at Placerville, California.

172. Little, Elbert L., Jr., Silas Little, and Warren T. Doolittle.
1967. **Natural hybrids among pond, loblolly, and pitch pines.** USDA Forest Serv. Res. Paper NE-67. 22 pp., illus. NE. Forest Exp. Sta., Upper Darby, Pa.

Discusses the comparative characteristics of the three species and their hybrids, the importance of distinguishing the species in forestry practice, and the possible role of pitch-loblolly hybrids. Botanical descriptions of the species and hybrids are given, and their distribution is described, especially in the Northeast.

173. Little, S., and H. A. Somes.
1951. **No exceptional vigor found in hybrid pines tested.** USDA Forest Serv. NE. Forest Exp. Sta. NE. Res. Note 10. 4 pp. Upper Darby, Pa.

Hybrids of pitch X loblolly pine grew well on a poor site in New Jersey, but were outgrown by ordinary loblolly pine stock on a moister site in Maryland. Shortleaf X pitch hybrids grew slower than shortleaf pine stock of the same age, and many of these hybrids still had a prostrate form 6 years after planting in both states.

174. Lorenz, R. W., and J. N. Spaeth.
1953. **The growth of two hybrid pines tested in southern Illinois.** Univ. Ill. Agr. Exp. Sta. Forestry Note 38. 2 pp.

Shortleaf X pitch hybrids tried were worthless. Pitch X loblolly hybrids were more cold-hardy than loblolly and shortleaf pines, and almost equal in growth rate to shortleaf pine, but much slower than loblolly pine. Its cold-hardiness may make the pitch X loblolly hybrid valuable in Illinois.

175. Schmitt, Dan.
1968. **Performance of southern pine hybrids in south Mississippi.** USDA Forest Serv. Res. Paper SO-36. 15 pp., illus. S. Forest Exp. Sta., New Orleans, La.

Data on 6-year survival and growth of plantings that included pitch pine from New Jersey and hybrids of pitch and loblolly or pond pines. Survival and growth of these were relatively low.

FOREST ECOLOGY

Silvical Characteristics

176. Andresen, John W.

1957. **Precocity of *Pinus rigida* Mill.** Castanea 22: 130-134, illus.

Staminate flowers were observed in the greenhouse on one seedling 22 months old, and in the field on a 2-year-old seedling shortly after planting. Two 2-year-old seedlings bore female flowers that developed into mature cones. One cone yielded 18 seeds, only 1 viable. Two cones had 44 to 57 seeds, about half of which germinated.

177. Baker, Frederick S.

1949. **A revised tolerance table.** J. Forestry 47: 179-181.

In a survey of 55 foresters, species were classified by degree of tolerance. The majority called pitch pine intolerant; others called it intermediate; and still others classed it as very intolerant.

178. Brown, Harry P.

1912. **Growth studies in forest trees. I. *Pinus rigida* Mill.** Bot. Gaz. 54: 386-403, illus.

Describes cambial activity and the formation of double rings in pitch pine. Its histological characteristics do not differ widely from the normal for conifers. Growth near Ithaca, N. Y., began by 15 April in 20- to 25-year-old trees below the apical shoot and spread upward. Growth spreads down the main axis faster than along laterals, but spread is affected by conditions of insolation and other factors.

179. Cain, Stanley A.

1940. **The identification of species in fossil pollen of *Pinus* by size-frequency determinations.** Amer. J. Bot. 27: 301-308, illus.

From measurements of grain lengths (exclusive of wings) of 150 pollens of each of the 12 species of *Pinus* native to the eastern United States, size-frequency curves were developed. Grains of pitch pine pollen had a mean length of 61.9 microns and could not be separated from those of *P. palustris*.

180. Choi, S. K., and M. R. Kim.

1963. **Plus trees in Korea. II.** Korean Inst. Forest Genet. Res. Rep. 3: 85-94, illus.

Three selected pitch pines 25 years old were 12.4 to 16.6 m. tall and 25.1 to 25.9 cms. d.b.h.

181. Cook, David B.

1941. **The period of growth in some Northeastern trees.** J. Forestry 39: 956-959, illus.

Planted pitch pine 4½ feet tall grew 13.5 inches in height during

59 days, starting 12 May 1940 at Stephentown, Rensselaer County, New York.

182. Deevey, Edward S., Jr.
1939. **Studies on Connecticut lake sediments. I. A postglacial climatic chronology for southern New England.** Amer. J. Sci. 237: 691-724 illus.

Sizes of pollen grains of different species of pines are too variable and overlap, preventing accurate separation of pitch pine pollen grains from those of white, red, and jack pines. Pollen grains of pitch pine in this study were 39 to 55 microns long.

183. Dixon, Dorothy.
1961. **These are the champs. Part II.** Amer. Forests 67(2): 41-47, illus.

A pitch pine near Mays Landing, N.J., was reported to be 97 feet tall, with a circumference of 8 feet 3 inches.

184. Dorman, Keith W., and John C. Barber.
1956. **Time of flowering and seed ripening in southern pines.** USDA Forest Serv. SE. Forest Exp. Sta. Sta. Paper 72. 15 pp., illus. Asheville, N. C.

In 1954 pitch pine pollen ripened between 29 April and 11 May in Buncombe County, N. C., at a 2,300-foot elevation; between 8 April and 29 April in California at a 2,700-foot elevation.

185. Duffield, J. W.
1953. **Pine pollen collection dates—annual and geographic variation.** USDA Forest Serv. Calif. Forest and Range Exp. Sta. Res. Note 85. 9 pp. Berkeley, Calif.

Over a 6-year period the collection of pitch pine pollen at Eddy Arboretum varied from 17 April to 10 May, with a mean date of 26 April.

186. Emig, W. H.
1935. **The megagametophyte of *Pinus*. I. Introduction.** Amer. J. Bot. 22: 500-503, illus.

Describes stages in the development of the gametophyte of *Pinus*. The percentage of viable seeds depends on seasonal differences and may be less than 1 percent of the ovules in pitch pine. Continued growth of the gametophyte depends on food supply from digestion of nucellus, which requires an adequate supply of water. Extent of development in ovules aborting at different ages is described.

187. Ferguson, Margaret C.
1904. **Contributions to the knowledge of the life history of *Pinus* with special reference to sporogenesis, the development of the gametophytes and fertilization.** Wash. Acad. Sci. Proc. 6: 1-202, illus.

A report on a detailed study of pollen grains, ovules, and of fertilization, with frequent references to and numerous illustra-

tions of pitch pine. Pistillate cones collected in mid-March consisted of broad axis with marginal bract initials, but no evidence of ovules. Ovules were apparent in cones collected in late April to early May, and by 8 May nucellus and integument were differentiated. Number of archegonia per ovule varies from one to five, but usually is three. Mitosis of antheridial cells was observed from mid-April to mid-May. Pollen grains germinate and tubes develop within 2 days of pollination.

188. Fowells, H. A.

1965. **Silvics of forest trees of the United States.** U. S. Dep. Agr. Agr. Handb. 271. 762 pp., illus.

Contains a revision of the paper by S. Little (1959), dealing with the silvical characteristics of pitch pine. It includes a revised map of the range of pitch pine.

189. Gifford, John.

1896. **Forest fires in New Jersey.** Franklin Inst. J. 142: 102-110.

Dormant buds along the boles of large pitch pines may sprout after a fire or after the stem is cut.

190. Illick, J. S.

1919. **When trees grow.** Pa. Forest Leaves 17: 60-64.

In Pennsylvania, pitch pine often begins a second period of terminal growth 10 to 25 days after the first growth ceases. As a result, fictitious rings are formed.

191. Kienholz, Raymond.

1934. **Leader, needle, cambial, and root growth of certain conifers and their interrelations.** Bot. Gaz. 96: 73-92, illus.

Near Keene, N. H., 97 percent of the leader elongation of pitch pine occurred between 15 May and 15 July. Needle elongation began about 15 May, reached a maximum in late June, and ceased in early September. The needles grew from a meristematic region at their base and did not elongate during the second year.

192. Little, S.

1941. **Calendar of seasonal aspects for New Jersey forest trees.** Pa. Forest Leaves 31(4): 1-2, 13-14, illus.

On the basis of 3 years' observations, dates are given for the times when staminate flowers become visible, leaf buds burst, leader growth begins, pistillate flowers are visible, pollen-shedding begins and ends, leaves and fruit are full grown, and seed dispersal begins and ends. Pitch pine, shortleaf pine, Atlantic white-cedar, and eight associated hardwoods are included. Effects of exposure, tree size, frost, and individual variation are discussed.

193. Little, S.

1959. **Silvical characteristics of pitch pine (*Pinus rigida*).** USDA Forest Serv. NE Forest Exp. Sta. Sta. Paper 119. 22 pp., illus. Upper Darby, Pa.

Describes the range; habitat conditions (climate, soils, physiographic, and biotic relations—including use by deer, rabbits, birds, mice, and squirrels; the associated trees, shrubs, fungi, and insects); seeding habits, including flowering, fruiting, seed production, and dissemination; vegetative reproduction; seedling establishment and growth; root development; growth and yield; reaction to competition; damaging agents and their effects; use for naval stores; and the hybrids and races of pitch pine.

194. Little, Silas, and Francois Mergen.

1966. **External and internal changes associated with basal-crook formation in pitch and shortleaf pines.** Forest Sci. 12: 268-275, illus.

Successive sketches show changes in basal form of 10 pitch pine and 22 shortleaf pine seedlings through their first 6 years or until the seedling died. Only one pitch pine did not form a basal crook. Many seedlings formed incipient crooks during the first summer; others a year or more later. Stem form continued to change for 2 to 10 years. Changes were explained on the basis of weak stems, usually upright apical growth, and formation of compression wood and eccentric growth rings. Sections showed heterogeneous alinement of wood fibers.

195. Little, S., and H. A. Somes.

1951. **Age, origin, and crown injuries affect growth of South Jersey pines.** USDA Forest Serv. NE. Forest Exp. Sta. Res. Note 8. 4 pp. Upper Darby, Pa.

Response of pitch and shortleaf pines after cutting oaks from an oak-pine stand varied. Overstory pines 6 to 13 inches d.b.h. doubled their rate of diameter growth. Old advance reproduction 5 to 16 feet tall also doubled their rates of diameter growth, but had little response in height growth because of flat tops. Seedlings established just before cutting had the best height growth after cutting.

196. Little, S., and H. A. Somes.

1956. **Buds enable pitch and shortleaf pines to recover from injury.** USDA Forest Serv. NE. Forest Exp. Sta. Sta. Paper 81. 14 pp., illus. Upper Darby, Pa.

Pitch pines sheared in August developed needle-fascicle buds and subsequent shoots both on current-year and previous-year growth (last when all of current-year growth was removed). The length of time pitch pines take to form well-developed basal crooks, and their importance in protecting basal buds and permitting sprouting after fires, are also described. Pitch pines sprouted at the base up to about 80 years of age, and the ages of boles at points where living buds were found also ran up to about 80 years. Pitch pine sprouts to far greater age than shortleaf, and consequently its sprouts vary much more in form and rate of growth.

197. Little, S., and H. A. Somes.

1964. **Root systems of direct-seeded and variously planted**

loblolly, shortleaf, and pitch pines. USDA Forest Serv. Res. Paper NE-26. NE. Forest Exp. Sta. 13 pp., illus. Upper Darby, Pa.

Root systems were developed normally only on plants from direct seeding. Amount of distortion of root systems varied with planting method, but seedlings in all planting methods had intertwined roots. Root systems of 1-0 stock recovered more from planting distortions than did 2-0 stock.

198. McIntyre, A. C.

1932. **Seeding habit of pitch pine.** Pa. Forest Leaves 23: 109-111.

A detailed description of serotinous cones in relation to portion of crown in which they grew on one tree. Cones from the middle portion of the crown produced the greatest number of viable seed. The lower third of sampled cones produced no seed, and the upper third of the cones yielded less than the middle.

199. McQuilkin, William Everett.

1935. **Root development of pitch pine, with some comparative observations on shortleaf pine.** J. Agr. Res. 51: 983-1016, illus.

Describes root systems at different stages from seedlings to mature trees on the basis of specimens excavated in southern New Jersey. Extensive root growth was found below the water table in saturated soils. On heavier soils, root development is less extensive than in the Coastal Plain. Shortleaf pine develops a stronger taproot and fewer supporting roots than pitch pine.

200. Moore, E. B.

1936. **Seedling-sprout growth of shortleaf and pitch pine in New Jersey.** J. Forestry 34: 879-882.

Seedling sprouts from natural reproduction of pitch pine and from shortleaf pines 2 years after planting 2-0 stock showed good survival and growth. More sprouts of pitch pine than of shortleaf pine reached heights of 5 to 9 feet in a 4-year period.

201. Namkoong, Gene.

1960. **Female flowers on 1-year-old pitch pine.** Forest Sci. 6: 163, illus.

Four flowers were found on three out of 20 potted seedlings of an intraspecific hybrid 12 months from seed.

202. Pak, T. S.

1966. **A study on growth in a young pitch pine stand originated from the sprouts and plantation.** Seoul Nat. Univ. Forests Bull. 3: 21-29, illus. Korea.

Sprouts from 17-year-old stumps outgrew planted seedlings in height for 4 years, and also in diameter, but differences were small. Growth of sprouts and of planted seedlings tend to become equal in both height and diameter.

203. Perry, George S.

1931. **Pine needles and oak leaves.** Pa. Forest Leaves 23: 22-23.

An acre of pitch pine forest in Pennsylvania had about 63 million needles weighing less than 2½ tons in a green condition during the winter. This is much less foliage than is borne by red or white pines.

204. Pomeroy, Kenneth B., and Lorna C. Littlecott.
1967. **The social register—85 new champs.** Amer. Forests 73(9): 28-33, illus.

The largest reported pitch pine, found near Hiddenite, N. C., was 9 feet 11 inches in circumference, 88 feet tall, and had a 50-foot spread in 1967.

205. Potzger, J. E.
1937. **Vegetative reproduction in conifers.** Amer. Midland Natur. 18: 1001-1004, illus.

Pitch pine is listed among species capable of vegetative reproduction.

206. Righter, F. I.
1939. **Early flower production among the pines.** J. Forestry 37: 935-938, illus.

The minimum age at which staminate or ovulate flowers are borne on pitch pines at the Institute of Forest Genetics in California is given as 4 years.

207. Stone, Earl L., Jr., and Margaret H. Stone.
1943. **Dormant buds in certain species of *Pinus*.** Amer. J. Bot. 30: 346-351, illus.

Stem sprouts of pitch pine arise from small buds at intermediate nodes of multinodal stems, as well as from small lateral buds at winter nodes—buds that remain dormant for a few years. These buds usually become small short branches bearing isolated or few fascicles, but are capable of forming long branches after injury to the tree. Such short shoots bear lateral buds that often remain dormant for a long time.

208. Stone, E. L., Jr., and M. H. Stone.
1954. **Root collar sprouts in pine.** J. Forestry 52: 487-491, illus.

In pitch pine small buds occur in the axils of primary needles above the cotyledons, and none of the buds or sprouts examined were adventitious. Basal buds like those of the upper stem often branch abundantly.

209. Zon, Raphael, and Henry S. Graves.
1911. **Light in relation to tree growth.** USDA Forest Serv. Bull. 92. 59 pp., illus.

Pitch pine is ranked as intermediate in tolerance of shade among eastern tree species.

Atmospheric and Biotic Relations (including fire)

210. Alderman, O. A.

1958. **Ohio trees. Pitch pine, *Pinus rigida* Miller.** Ohio Conserv. Bull. Feb.: 24, illus.

Briefly describes the range, appearance, and wood quality of pitch pine, and its relation to fire. This pine is used to some extent to reforest land in eastern Ohio.

211. Brown, James H., Jr.

1959. **Effect of fire on Rhode Island woodlands.** R. I. Agr. 5(4): 3, illus.

Briefly mentions that pitch pine is favored by or dependent upon fire for its existence.

212. Brown, James H., Jr.

1960. **The role of fire in altering the species composition of forests in Rhode Island.** Ecol. 41: 310-316, illus.

Pitch pine occurs abundantly on burns in several localities on extremely droughty soils.

213. Buell, Murray F., and John E. Cantlon.

1953. **Effects of prescribed burning on ground cover in the New Jersey Pine Region.** Ecol. 34: 520-528, illus.

In prescribed burning to favor pitch and shortleaf pines, the shrub cover is greatly reduced—especially *Gaylussacia.* Subsequent cutting of trees results in an increase in cover for shrub, herb, and moss layers; but the increase is greatest on areas most frequently burned. However, cutting caused a decrease in cover by *G. baccata.*

214. Burnham, C. F , M. J. Ferree, and F. E. Cunningham.

1947. **The scrub oak forests of the Anthracite Region.** USDA Forest Serv. NE. Forest Exp. Sta. Sta. Paper 4. 9 pp., illus. Upper Darby, Pa.

As a result of repeated fires, about 231,500 acres of the Anthracite Region of Pennsylvania have scrub oak forests in which the usual vegetation is chiefly blueberries, scrub oaks, and scattered pitch pines. With fire protection, scrub oak is replaced, most frequently by sassafras, red maple, chestnut oak, and red oak.

215. Clarke, W. S.

1946. **Effect of low temperatures on the vegetation of the barrens in central Pennsylvania.** Ecol. 27(2): 188-189.

In the barrens of Centre County, the higher land originally had an oak-chestnut forest; the lower ground bore mostly conifers, including pitch pine. Though scrub oaks were common on both sites after lumbering and fires, large oaks now prevail on the high ground. In the valley pitch pine is common, but scrub oaks predominate. Low temperatures every year in winter or spring are suggested to explain the absence of large oaks in the valley.

216. Fernow, B. E.

1895. **A coppice of pine.** Gard. and Forest 8: 472-473.

Briefly describes vegetation of the New Jersey Pine Barrens, including that in Plains growth (which covers about 15,000 acres), and also discusses the sprouting of pitch pine. Because a road bounded one portion of the Plains, repeated fires may be the cause of stunted growth there.

217. Hepting, George H.

1966. **Air pollution impacts to some important species of pine.** J. Air Pollut. Contr. Assoc. 16(2): 63-65.

Smoke from a manufacturing plant's trash burner severely injured large pitch mines in the surrounding wooded basin.

218. Little, S.

1946. **The effects of forest fires on the stand history of New Jersey's Pine Region.** USDA Forest Serv. NE. Forest Exp. Sta. Forest Manage. Paper 2. 43 pp., illus.

Original stands were probably composed mostly of large pines, and as a result of Indian fires had little undergrowth. Varying damage from different types of fires in oak-pine (pitch and shortleaf), in pitch pine-scrub oak, and in lowland pitch pine stands is described, as is the effect of past fires on present composition. Pre-settlement fires were of low intensity and usually permitted the development of good-quality stands. More recent fires have been less frequent, but have greatly damaged forest composition and quality.

219. Little, Silas.

1952. **Effects of forest fires on upland sites in the Pine Region of southern New Jersey.** N. J. Coll. Agr. Ext. Serv. Leafl. 100. 8 pp., illus.

Pine stands that develop on cleared land are replaced by hardwoods, chiefly oaks, because the latter are more shade-tolerant and can become established in thick litter. Differences in fire damage to pitch and shortleaf pines and to oaks are described, as is the role of wild fires in shaping present stand composition and quality — from Plains to oak-pine stands. The role of light frequent fires in the original forest and in present-day management is mentioned.

220. Lutz, Harold J.

1934. **Ecological relations in the pitch pine plains of southern New Jersey.** Yale Univ. School Forestry Bull. 38. 80 pp., illus.

In the Pine Barren region are Plains areas of dense low growth of pitch pine and bear oak, where stems are less than 11 feet tall. This bulletin contains data on plant composition, age, and height; on evaporation and surface soil temperatures; on soil analyses; and on fire history at 16 Plains and 18 other Pine Barren stations. The detailed study refuted hypotheses attributing Plains growth to geological, climatic, or soil differences. Repeated killing fires are the cause for present composition, predominance of sprouts, and young age of existing stems.

221. McCormick, Jack, and Murray F. Buell.

1968. **The Plains: pigmy forests of the New Jersey Pine Barrens, a review and annotated bibliography.** N. J. Acad. Sci. Bull. 13(1): 20-34, illus.

A review of knowledge about composition, location and extent, and cause of the Plains vegetation, and a new definition to distinguish it from other Pine Barren vegetation.

222. Moul, Edwin T., and Murray F. Buell.

1955. **Moss cover and rainfall interception in frequently burned sites in the New Jersey Pine Barrens.** Torrey Bot. Club Bull. 82: 155-162.

Periodic prescribed fires to favor pine (pitch and shortleaf) stands also favor the development of a bryophyte-lichen layer. This may cover 33 percent or more of the ground. Three species formed 98 percent of the moss cover.

223. Perry, George S.

1931. **Pitch pine as a rain-maker.** Pa. Forest Leaves 23(3): 43-45.

Condensation of moisture on pitch pine needles during a foggy period of 1 or 2 days in December was estimated to have added 15,320 gallons of water per acre to the soil of a pine forest, or possibly 5,100 gallons per acre to streamflow, in the vicinity of Mont Alto, Pennsylvania. In contrast, no condensation was observed on the associated bear and chestnut oaks.

224. Pinchot, Gifford.

1900. **The Plains.** N. J. State Geol. Annu. Rep. 1899: 124-130, illus.

Describes briefly the vegetation, mentioning that pitch pine stems on much of the Plains are only 2 to 4 feet tall, but sometimes reach 6 to 14 feet and rarely up to 25 feet in height. Relatively young sprout growth predominates, but there are some seedlings. Stumps that cease to sprout have main roots 40 to 100 years old. Origin of the Plains stands is attributed to fire, and exposure and poor soil are given as the reason for the prostrate form of most stems.

225. Wood, O. M.

1937. **The interception of precipitation in an oak-pine forest.** Ecol. 18: 251-254.

In the New Jersey Pine Barrens, rain gages were installed under a chestnut oak, under a pitch pine, under a white oak partly overtopped by a pitch pine, and under a blackgum overtopped by a chestnut oak and a pitch pine. Over a 17-month period the catch under trees was 85 to 91 percent of that in the open, but the proportion varied with type, intensity, and duration of precipitation.

226. Woodwell, G. M., and A. L. Rebuck.

1967. **Effects of chronic gamma radiation on the structure and diversity of an oak-pine forest.** Ecol. Monogr. 37: 53-69, illus.

An oak-pine forest in central Long Island has been irradiated chronically with gamma radiation during 4 years, and four new vegetation zones were created: one where all indigenous higher plants have been killed; a zone where *Carex pensylvanica* was the principal survivor; a shrub zone where *Carex* and ericaceous shrubs survived; and an oak forest where pines have been killed (and finally the zone where the oak-pine forest is intact). Large pitch pines were more susceptible than small ones, because their crowns were more exposed.

Edaphic and Geological Relations

227. Allard, H. A.

1946. **Shale barren associations on Massanutten Mountain, Virginia.** Castanea 11: 72-124, illus.

On the barrens pitch pine grows with Virginia and table-mountain pines and chestnut oaks. Pitch and Virginia pines are the dominant invaders of old pastures.

228. Andresen, John W.

1959. **A study of pseudo-nanism in *Pinus rigida* Mill.** Ecol. Monogr. 29: 309-332, illus.

Data from this study show that the primary cause of dwarf pitch pine sprouts (Plains growth) in parts of the New Jersey Pine Barrens is repeated fires, not toxic amounts of soluble aluminum in the soil. From observations after cutting trees of different ages, sprouts of the younger trees had the best vigor and form. Soluble aluminum did not depress growth of pitch pine, which is classed in this study as an aluminum accumulator.

229. Bernard, John M.

1963. **Forest floor moisture capacity of the New Jersey Pine Barrens.** Ecol. 44: 574-576, illus.

Litter cover varied from 86 to 100 percent in the 12 communities studied, all of which were composed of mixtures of pitch and shortleaf pines with various oaks. Litter depths ranged from 0.5 to 0.9 inches, and the forest floor can hold about 0.5 inch of water.

230. Blair, A. W., and A. L. Prince.

1925. **The chemical composition of the soils of the Chatsworth area in New Jersey.** N. J. Agr. Exp. Sta. Bull. 414. 15 pp., illus.

Lakewood soils were among the least productive surveyed, and Leon soils also were called unproductive. Most of these two series are covered by forests of pitch pine. This report gives percentages of nitrogen, phosphoric acid, potash, lime, and magnesia, and the pH of individual samples by soil series.

231. Blankinship, J. W.

1903. **The plant-formations of eastern Massachusetts.** Rhodora 5: 124-137.

Pitch pine occurs in the Hilltop-Barren Formation (high points of slate or granite or cliffs) and in the Sand-Plain Forest Formation. Other species in these formations are listed.

232. Bray, William L.

1921. **History of forest development on an undrained sand plain in the Adirondacks.** N. Y. State Coll. Forestry Tech. Pub. 13. 47 pp., illus.

Pitch pine is the dominant species of the Hudson-Mohawk, Saranac, and Black River sand plains, following destruction of an apparently edaphic climax of white pine.

233. Bray, William L.

1930. **The development of the vegetation of New York State.** N. Y. State Coll. Forestry Tech. Pub. 29. 189 pp., illus.

Pitch pine is mentioned as occurring in the Plattsburg sand barrens, Hudson-Mohawk pine barrens, Long Island pine barrens, and on summits of the Shawungunk Mountains — presumably edaphic conditions providing suitable sites for pitch pine and associated pine barren flora.

234. Brierly, William B.

1938. **The relation of *Pinus rigida* to physiographic features and soil types in central Massachusetts.** Rhodora 40: 72-73.

In Worcester County pitch pine occurs almost exclusively on sandy and gravelly soils of the Merrimac and Hinckley series, soils developed from stratified glacial deposits.

235. Broadfoot, W. M., and W. H. Pierre.

1939. **Forest soil studies: I. Relation of rate of decomposition of tree leaves to their acid-base balance and other chemical properties.** Soil Sci. 48: 329-348, illus.

The pH, and content of nitrogen, calcium, ash, and water-soluble organic matter are given for two samples of West Virginia pitch pine litter. The litter of this species was among the slowest to decompose.

236. Buell, Murray F., Arthur N. Langford, Donald W. Davidson, and Lewis F. Ohmann.

1966. **The upland forest continuum in northern New Jersey.** Ecol. 47: 416-432, illus.

Pitch pine is the most characteristic pioneer species of dry exposed ridge tops. Its presence as a dominant depends on fire.

237. Cantlon, John.

1951. **A preliminary investigation of the influence of prescribed burning on soil water supplies in South Jersey.** Annu. Conv. Amer. Cranberry Growers' Assoc. Proc. 82: 18-26, illus. (Reprinted with corrections).

In pitch-shortleaf pine and oak stands of the New Jersey Pine Barrens, throughfall of precipitation was measured for 4 months (6 July to 15 November) under pines, oaks, and trees plus shrubs. Soil moisture was sampled twice weekly from 15 June to 15 August at 20- and 70-cm. levels in annually burned and unburned oak-pine stands. Throughfall under pine was less than under oak, but only slightly less than under oak plus shrubs. Effects on soil moisture from prescribed burning were inconclusive.

238. Colvin, Walter S., and Walter S. Eisenmenger.
1943. **Relationships of natural vegetation to the water-holding capacity of the soils of New England.** Soil Sci. 55: 433-446, illus.

On light soils with low water-holding capacity in both A and B horizons, characteristic plants include pitch pine, black oak, scrub oak, broomsedge, sweetfern, certain legumes, and other herbs.

239. Frothingham, E. H.
1924. **Forest research.** J. Forestry 22: 343-352.

In the southern Appalachians, pitch pine is one of the species found on ridges and dry, usually southerly slopes.

240. Garstka, Walter Urban.
1932. **The calcium content of Connecticut forest litter.** J. Forestry 30: 396-405, illus.

Pitch pine is described as a physiographic climax. On the basis of three or four samples of the 12 types studied, pitch pine litter had a very low ash content and the lowest calcium content (0.35 percent of litter weight).

241. Hawley, R. C., E. I. Terry, and K. W. Woodward.
1922. **Forest region and type classification for New England.** J. Forestry 30: 122-129.

The pitch pine type is of minor commercial importance, and occurs in central and southern New England on the poorest and driest sandy soils.

242. Hobbs, Clinton H.
1940. **Symptoms of mineral deficiency in pine.** Amer. J. Bot. 27, Supp. 10: 16.

In nutrient sand cultures lacking singly each of the major elements, deficiency symptoms for nitrogen, phosphorus, and potassium developed within 5 weeks; those for magnesium not until 3 months after germination. No deficiency symptoms for iron, boron, and manganese were observed in this 6-month study of pitch and red pines.

243. Hollick, Arthur.
1899. **The relation between forestry and geology in New Jersey.** Amer. Natur. 33: 1-14, illus.

In the coniferous zone (Pine Barrens), pitch pine predominates, often almost exclusively over extensive areas. The northern border of this zone is reported as coterminous with the northern border of Tertiary gravels, sands, and sandy clays. The tension zone has many more hardwoods and includes nearly all Cretaceous and Tertiary deposits of plastic clays, clay-marls, and marls.

244. Hollick, Arthur.

1900. **The relation between forestry and geology in New Jersey.** N. J. State Geol. Annu. Rep. 1899: 173-201, illus.

The northern edge of the coniferous zone in southern New Jersey coincides with the northern border of the Tertiary sands and gravels. Pitch pine is exceedingly abundant in the coniferous zone, less abundant in the tension zone, and forms only scattered groves or individuals in the deciduous zone. Pitch pine is better able to compete with other species on the poor soils of the coniferous zone than on richer soils, even though best growth of pitch pine is on the latter sites.

245. Hope, John G.

1943. **An investigation of the litter fauna of two types of pine forest.** Wagner Free Inst. Sci. Bull. 18: 1-7.

In one pitch pine stand of the New Jersey Pine Barrens, 138,112 animals per square meter were found in the litter and humus layers. Mites (Acarina) formed about 63 percent of the fauna, springtails (Collembola) about 37 percent. Ants, beetles, bugs, bristleworms, Diptera flies, centipedes, snails, etc., were also present.

246. Illick, Joseph S.

1921. **Replacement of the chestnut.** J. Forestry 19: 105-114.

Pitch pine was one of the chestnut associates on dry hillside sites, and with a little care it can be favored in considerable quantity to form new stands replacing chestnut on such sites. Where natural reproduction is insufficient, planting of pitch pine or other pines is recommended.

247. Joffe, J. S., and C. W. Watson.

1933. **Soil profile studies: V. Mature podzols.** Soil Sci. 35: 313-329, illus.

Descriptions and analysis of two podzol profiles of Lakewood soils in the New Jersey Pine Barrens, both from areas where pitch pine predominates. The authors suggest that the high amount of aluminum in one soil is a contributing factor to its unproductivity for pitch pine.

248. Kelley, Arthur Pierson.

1927. **Dune formation by Pine Barren plants.** Bot. Gaz. 83: 89-93, illus.

Suggests that secondary hills in the New Jersey Pine Barrens were formed by sand-binding plants, especially pitch pines with bushy basal whorls of branches.

249. Lounsbury, Clarence, F. B. Howe, R. E. Zautner, W. J. Moran, and P. D. Beers.

1933. **Soil survey of Suffolk and Nassau Counties, New York.** USDA Bur. Chem. and Soils Series 1928, 28: 1-46, illus.

A few pitch pines grow along the north shore of Long Island, but pitch pine is the dominant tree growth on many of the sandier soils (as Sassafras sandy loam) of the central and southern sections.

250. Lowry, Gerald L.

1960. **Conifer growth is best on acid spoils.** Ohio Farm and Home Res. 45: 44, illus.

Pitch pine grows well on sandy spoils and those with a loose shaly surface if soil acidity is between pH 3.5 and 5.8.

251. Lunt, Herbert A.

1948. **The forest soils of Connecticut.** Conn. Agr. Exp. Sta. Bull. 523. 93 pp., illus. New Haven, Conn.

Contains data on weights of forest floors under different forest types, results of analyses for physical and chemical properties, descriptions of typical profiles, and effects of agriculture and fire. Pitch pine is occasionally mentioned, as in summarizing Garstka's (*1932*) data on the F layers of forest floors.

252. Lutz, H. J.

1934. **Concerning a geological explanation of the origin and present distribution of the New Jersey pine barren vegetation.** Ecol. 15: 399-406, illus.

Refutes hypothesis developed by Hollick, Harshberger, and Taylor that the Pine Barrens were coextensive with geological formation and the vegetation was due to isolation on a Pensauken Island. Shows that Pine Barren vegetation occurs on several formations, and island hypothesis is no longer accepted.

253. McIntyre, Arthur C., and J. W. White.

1930. **The growth of certain conifers as influenced by different fertilizer treatments.** J. Amer. Soc. Agron. 33: 558-567.

On a Hagerstown silt loam in Pennsylvania, the three fertilizers that produced the most organic matter in 2-year-old pitch pine seedlings were in descending order: 400 lbs./acre of dried blood, 400 lbs./acre of ammonium sulfate, and a combination of 800 lbs. superphosphate and 200 lbs. of muriate of potash. Some of the other fertilizer treatments produced lighter seedlings than the checks.

254. McIntyre, A. C., and J. W. White.

1932. **Fertilizing coniferous seedlings.** J. Amer. Soc. Agron. 24: 72-73.

Dried blood fertilizer at 400 pounds per acre produced larger and heavier pitch pine seedlings than other mineral fertilizers during a 4-year period.

255. Maull, Theodore Ward.

1963. **Seed germination and establishment of *Pinus rigida* Miller (an autecological study).** Diss. Abstr. 23: 3607-3608.

In the Barrens of central Pennsylvania there is abundant seed production by pitch pine, but a paucity of natural reproduction. This study dealt with (1) factors affecting the germination of pitch pine seeds (temperature, relative humidity, period of imbibition necessary, drying after soaking, light, pH, soil moisture) and (2) soil-moisture conditions under different covers in the Barrens. Scarcity of pitch pine seedlings in the Barrens is attributed to unfavorable soil and air temperatures and unfavorable soil moisture.

256 Melin, Elias

1930. **Biological decomposition of some types of litter from North American forests.** Ecol. 11: 72-101, illus.

Fairly active early decomposition of pitch pine litter in spite of low N content may be due to high content of water-soluble substances, chiefly sugars. After 4 months 30 percent of the organic matter had decomposed, including 87 percent of the water-soluble substances, 16 percent of the water-insoluble substances, and 45 percent of the hemicelluloses and celluloses.

257 Plice, Max J.

1934. **Acidity, antacid buffering, and nutrient content of forest litter in relation to humus and soil.** Cornell Univ. Agr. Exp. Sta. Mem. 166, 32 pp., illus.

Pitch pine litter from an area in Pennsylvania and one in New York was relatively low in CaO content (0.8 or 0.5 percent) and in mineral base content, and lowest in nitrogen content (0.6 percent) of 26 species studied. Pitch pine litter was placed in a group having low bases and buffer but strong acidity.

258 Radford, Albert E.

1948. **The vascular flora of the olivine deposits of North Carolina and Georgia.** Elisha Mitchell Sci. Soc. J. 64: 45-106, illus.

Describes plants found in "pine-andropogon" and "pine-oak" communities, both of which frequently include pitch pine among the dominants. The "pine-andropogon" community is xerophytic, occurring on southern slopes.

259 Raup, Hugh M.

1938. **Botanical studies in the Black Rock Forest.** Black Rock Forest Bull. 7, 161 pp., illus.

A scrub oak-pitch pine association occupies nearly every hilltop above 1,200-foot elevation in Black Rock Forest, Orange County, N. Y.—especially on southerly and westerly exposures. Associated species are mentioned.

260 Richards, B. N., and G. K. Voigt

1965. **Nitrogen accretion in coniferous forest ecosystems.** *In* **Forest-soil relationships in North America.** Second North Amer. Forest Soils Conf. (Oreg. State Univ. Press), 105-116.

Soil beneath 12 pitch pines 5 to 9 years old contained a higher percentage of total N than soil uninfluenced by such trees. Yet soil N reserves were inadequate to account for all the N found in trees. The fixation of atmospheric N in association with *Pinus* is suggested.

261 Taylor, Norman

1912. **On the origin and present distribution of the Pine Barrens of New Jersey.** Torreya 12: 229-242, illus.

Present composition of the Pine Barren vegetation is ascribed to the isolation of a remnant of more extensive distribution of pine barrens on a Miocene island. (Author's geological explanation of the origin and present distribution of the New Jersey Pine Barrens was later refuted.)

262. Tedrow, J. C. F.
1952. **Soil conditions in the Pine Barrens of New Jersey.** Bartonia 26: 28-35, illus.

These soils are formed of extremely sandy materials, with some gravel, and are usually true podzols. The Pine Barrens are due primarily to the character of geologic materials, but there is no good correlation with geologic formations. Amount of soluble aluminum is reported higher in the Plains than in the Barrens, and was considered sufficient to have a serious toxic effect on vegetation. (See Andresen 1959).

263. Voigt, G. K.
1966. **Phosphorus uptake in young pitch pine (*Pinus rigida* Mill.).** Soil Sci. Soc. Amer. Proc. 30: 403-406, illus.

Average annual P requirements of pitch pine were approximated by acid-extracting agents, but water-soluble P in the root-surface zone was less than annual uptake. P uptake was apparently reduced by increasing Ca concentration, and increased with increased root surface.

264. Voigt, G. K., B. N. Richards, and E. C. Mannion.
1964. **Nutrient utilization by young pitch pine.** Soil Sci. Soc. Amer. Proc. 28: 707-709, illus.

Ten pitch pines 5 to 9 years old were excavated from an abandoned gravel pit in southern New Jersey. Annual uptake of K was approximately equal to exchangeable K content of root-surface sorption zone; similar uptake of Ca was about one-third of exchangeable Ca in the same zone. Less than 10 percent of the total soil volume occupied by roots was utilized in absorption of Ca and K.

265. Wherry, Edgar T.
1922. **Soil acidity preferences of some eastern conifers.** J. Forestry 20: 488-496.

Pitch pine is listed among conifers preferring acid habitats, is especially characteristic of acid New Jersey Pine Barrens, and less commonly grows on clayey or sandy soils that have neutral reactions at moderate depths.

266. Wherry, Edgar T.
1932. **Ecological studies of serpentine-barren plants. I. Ash composition.** Pa. Acad. Sci. Proc. 6: 32-38.

The ash of pitch pine growing near Atsion, Burlington County, N. J., and of pitch pine from serpentine barrens near Nottingham, Chester County, Pa., showed that the latter contained markedly less total ash and potash, but much more magnesium oxide.

267. Williams, Clarence R.
1929. **The pine barren "island" of New Jersey.** Amer. Bot. 35: 49-55.

Attributes the dominance of pine barren vegetation in the New

Jersey Pine Barrens to the area's being an island in early glacial times. (See Lutz, 252.)

268. Wood, O. M.

1933. **Litter cover and soil surface temperatures, oak-pine type.** USDA Forest Serv. Allegheny Forest Exp. Sta. Tech. Note 3. 1 p.

Litter cover reduced high surface soil temperatures under an oak-pine (pitch?) stand in southern New Jersey. Decreasing moisture content of surface soil increased its temperature.

269. Woodwell, G. M., and T. G. Marples.

1968. **The influence of chronic gamma irradiation on production and decay of litter and humus in an oak-pine forest.** Ecol. 49: 456-465, illus.

Gives the amount of organic matter in litter and humus of unaffected forest, annual input of litter, rates of decay in litter and humus, and effects of irradiation. Sensitivity of pitch pine as measured by litter fall is complicated by (1) usual persistence of leaves through second summer and (2) litter from currently dying trees. Exposure causing 50-percent reduction in pitch pine leaf fall declined from 29 r/day in 1962-63 to possibly 4 r/day in 1965-66. Some indications that, under continued exposure, damage to oaks and pines becomes similar after several years.

Plant Sociology

270. Allard, H. A., and E. C. Leonard.

1943. **The vegetation and floristics of Bull Run Mountain, Virginia.** Castanea 8: 1-64, illus.

Pitch pine occurs frequently, often in pastures, with the more common Virginia pine — usually on dry, sandy slopes and ridges or on burned sites.

271. Archard, Howell O., and Murray F. Buell.

1954. **Life-form spectra of four New Jersey pitch pine communities.** Torrey Bot. Club Bull. 81: 169-175.

Compares one pine-dominated community and one oak-dominated community in the Lebanon State Forest, in the Pine Region of southern New Jersey, with two similar communities in High Point State Park in northwestern New Jersey. Seed plants predominate in each of the pitch pine communities, but there are more hemicryptophytes and cryptophytes (the more protected life forms) in the High Point area, which has the more severe climate. In both sections the oak stand had less open space in the tree canopy, but more in the shrub layer, than the pine stand.

272. Beckwith, Charles S., and Jessie G. Fiske.

1925. **Weeds of cranberry bogs.** N. J. Agr. Exp. Sta. Circ. 171. 23 pp., illus.

Pitch pine covered 3 percent of a neglected cranberry bog at an unnamed locality in southern New Jersey, about as much as that covered by gray birch, red maple, Atlantic white-cedar, or blackgum — the other tree species mentioned.

273. Braun, E. Lucy.
1935. **The vegetation of Pine Mountain, Kentucky: an analysis of the influence of soils and slope exposure as determined by geological structure.** Amer. Midland Natur. 16: 517-565, illus.

Pitch pine is a dominant species in pine and chestnut oak-pine types and occurs in some other types, all on southeast slopes. Pitch pine occurs in mixed stands on low ridges and on some sandstone soils; but as the soil becomes increasingly shallow, pitch and shortleaf or Virginia pines predominate. Associated species in the various conditions are listed. Pine and pine-oak communities are considered subclimax or physiographic climaxes.

274. Bromley, Stanley W.
1935. **The original forest types of southern New England.** Ecol. Monogr. 5: 61-89, illus.

Pitch pine originally dominated forests on the lighter, sandy soils of Cape Cod; oak prevailed on the better soils; oak-pitch pine in the tension zone. Pitch pine stands also prevailed on light sandy soils elsewhere in different parts of Massachusetts, Connecticut, and Rhode Island. Such stands were favored by frequent fires; and in the absence of fire, white pine and hemlock tended to supplant pitch pine in the northern portions, oaks to replace pitch pine in southern and southeastern sections.

275. Brown, Babette I.
1948. **A study of the distribution of epiphytic plants in New York.** Amer. Midland Natur. 39: 457-497, illus.

Ten lichens and two mosses were found as epiphytes on pitch pine.

276. Buell, Murray F., and John E. Cantlon.
1950. **A study of two communities of the New Jersey Pine Barrens and a comparison of methods.** Ecol. 31: 567-586, illus.

The place of pitch pine and associated trees and shrubs in the succession in two upland stands is discussed. The two communities, tending to be in the oak-pine and pine-scrub oak types, represent two stages of succession, and present composition is probably the result of differential disturbance due to fire.

277. Cain, Stanley A.
1931. **Ecological studies of the vegetation of the Great Smoky Mountains of North Carolina and Tennessee. I. Soil reaction and plant distribution.** Bot. Gaz. 91: 22-41, illus.

Pitch pine is one of the associated species in heath communities dominated by shortleaf and table-mountain pines. These communities occur on southern exposures of the lower ridges at an elevation of about 3,400 feet.

278. Chrysler, Mintin Asbury.
1905. **Reforestation at Woods Hole, Massachusetts. A study in succession.** Rhodora 7: 121-129, illus.

Describes the planting of pitch pine and other species at Woods Hole, as well as the direct seeding of pitch pine and some other conifers. Oaks are replacing pines, and along the coast pitch pines and Scotch pines are stunted, probably from wind-carried salt.

279. Conard, Henry S.

1935. **The plant associations of Central Long Island (New York).** Amer. Midland Natur. 16: 433-516, illus.

Pitch pine is the dominant species in a "Pinetum rigidæ" association, but is also found in some other Pine Barren associations and on Fire Island. Because of cuttings and fires, scrub oak has replaced former stands of pitch pine. Species associated with pitch pine are listed.

280. Davis, John H., Jr.

1930. **Vegetation of the Black Mountains of North Carolina: an ecological study.** Elisha Mitchell Sci. Soc. J. 45: 291-318, illus.

Pitch pine is a dominant member of the xeric slope and ridge association. Pines often occur in pure stands. Associated species are listed.

281. Day, Gordon M.

1953. **The Indian as an ecological factor in the northeastern forest.** Ecol. 34: 329-346.

From a comprehensive review of literature, Day concluded that in the Northeast Indians created sizeable clearings for villages and fields, and frequently moved to new sites. In many sections Indians also set fires to improve traveling, drive game, and for other reasons. Fires and the clearing and abandonment of fields modified composition and density of forests. Pitch pine land in New England may have been burned for over 1,000 years.

282. Donahue, William H.

1954. **Some plant communities in the Anthracite Region of northeastern Pennsylvania.** Amer. Midland Natur. 51: 203-231, illus.

In the scrub oak community occasional pitch pines jut above rest of vegetation, but play only a minor role in total cover (1.6 percent of overstory). Associated species are listed, and density and frequency of all plants given.

283. Eyre, F. H., W. A. Dayton, D. Den Uyl, R. C. Hawley, and P. R. Wheeler.

1954. **Forest cover types of North America (exclusive of Mexico).** 67 pp., illus. Soc. Amer. Foresters, Washington, D.C.

The pitch pine type occupies infertile ridges, flats and slopes, or coastal sands on dry to poorly drained sites. The type is considered temporary (resulting from fire) and succeeded by hardwoods. Pitch pine is listed as an associate in 12 other types: red pine, white pine, scarlet oak, bear oak, chestnut oak, white pine-chestnut oak, shortleaf pine, shortleaf pine-oak, shortleaf pine-Virginia pine, Virginia pine-southern red oak, Virginia pine, and Atlantic white-cedar.

284. Graham, H. W., and L. K. Henry.

1933. **Plant succession at the borders of a kettle-hole lake.** Torrey Bot. Club Bull. 60: 301-315, illus.

Lake levels near Wading River, Long Island, New York, fluctuate appreciably with precipitation, and consequently shore plant succession is periodically arrested or initiated. Pitch pine invades the higher zones, but is killed by rising water levels after 7 or 14 years.

285. Grandtner, Miroslav M.

1961. **Note sur le pinetum rigidae du Quebec.** Natur. Canad. 88: 39-44, illus.

Describes pitch pine stands on four different types of sites near Saint-Chrysostôme, Quebec. The appearance, composition, and value of these stands vary. Pitch pine fruits abundantly, is easily reproduced, and grows rapidly; but on only one of the sites does it become economically valuable.

286. Harper, Roland M.

1918. **A sketch of the forest geography of New Jersey.** Geog. Soc. Phila. Bull. 16(4): 107-125, illus.

The author mentions the occurrence of pitch pine on Kittatinny Mountain, in the Pine Barrens, in the Cohansey Region, on Cape May peninsula, and in the coastal dunes. Pitch pine is called the most abundant species, although it is less widely distributed than some hardwoods.

287. Harshberger, John W.

1916. **The vegetation of the New Jersey Pine-Barrens.** 329 pp., illus. Christopher Sower Co., Philadelphia.

The Pine-Barrens vegetation is described from phytogeographic and ecological aspects, including different associations in which pitch pine occurs, both inland and along the coast. Plains growth was attributed to impervious subsoil, strong winds, and protozoa destructive of bacteria (see Lutz, 220). Flowering and fruiting periods are given for different plants, as well as class of root system and detailed descriptions of leaf structure.

288. Hawley, R. C., E. I. Terry, and K. W. Woodward.

1922. **Revision of a report on a forest region and type classification for New England.** J. Forestry 20: 795-798.

The pitch pine forest type occurs in the white pine, Connecticut hardwoods, and Cape Cod regions. In the Cape Cod region the type may have a high percentage of scrub oak.

289. Henry, LeRoy K.

1930. **Ecological observations upon the flora of Wading River, Long Island, New York.** Pa. Acad. Sci. Proc. 4: 60-65.

Pitch pine barrens are confined to outwash plains, where soils are sands or coarse sandy loams. Pitch pine is the dominant species. Associated species are mentioned.

290. Henry, LeRoy K.

1932. **Ecological notes upon the flora of an old lake basin.** Pa. Acad. Sci. Proc. 6: 119-120.

In a kettle-hole basin near Wading River, Long Island, pitch pine grows on sloping sides and on higher tufts of sphagum moss in the central part. Associated species are mentioned.

291. Hotchkiss, Neil, and Robert E. Stewart.

1947. **Vegetation of the Patuxent Research Refuge, Maryland.** Amer. Midland Natur. 38: 1-75, illus.

Pitch pine forms nearly pure stands on old fields of poorly drained sandy sites and on well-drained terrace or upland sites, or sometimes occurs as an associate of sweetgum on the moister soils and of Virginia pine on the drier soils. On terraces pine stands later become pine-beech forests that yield to a beech-white oak mixture, while on upland sites the pine stands change to pine-oak and then to upland oak forests.

292. Howe, Clifton'Durant.

1910. **The reforestation of sand plains in Vermont.** Bot. Gaz. 49: 126-148, illus.

Pitch pine probably occurred in small scattered areas in the original stands, but became predominant after the first cutting. White pine, however, is replacing it on cut-over areas and in abandoned fields. Succession in both types of areas is described.

293. Jennings, O. E.

1926. **Classification of the plant societies of central and western Pennsylvania.** Pa. Acad. Sci. Proc. 1: 23-55, illus.

Pinus rigida is predominant in the pitch pine association, which occurs on dry ridge tops, and in the pine barrens (pitch pine-scrub oak association) in Centre and Huntingdon Counties. The species is a minor component of some other associations.

294. Korstian, C. F.

1924. **Natural regeneration of southern white cedar.** Ecol. 5: 188-191, illus.

Pitch pine is an associate of Atlantic white-cedar in the Northeast, as far south as New Jersey.

295. Korstian, C. F., and Paul W. Stickel.

1927. **The natural replacement of blight-killed chestnut.** U. S. Dep. Agr. Misc. Circ. 100. 15 pp., illus.

In Pennsylvania and New Jersey, pitch pine is among desirable but less common species replacing chestnut. In New England it seldom is associated with chestnut.

296. Lewis, I. F.

1924. **The flora of Penikese, fifty years after.** Rhodora 26: 181-195, illus.

Penikese, a small island 12 miles south of New Bedford, Mass., reportedly once had forest vegetation — pitch pine, red maple, hickory, birch, and associated species. Cutting of the original timber was followed by grazing of sheep, which eliminated these tree species. Sheep were removed in 1910, but pitch pine and most other tree species are still absent.

297. Little, Silas, Jr.

1950. **Ecology and silviculture of whitecedar and associated hardwoods in southern New Jersey.** Yale Univ. School Forestry Bull. 56. 103 pp., illus.

Pitch pine is one of the species that invade abandoned cranberry bogs, but is less tolerant than Atlantic white-cedar and hence is usually taller. In dry, usually sandy swamps, fires have favored pitch pine over white-cedar.

298. Little, S.

1951. **Observations on the minor vegetation of the Pine Barren swamps in southern New Jersey.** Torrey Bot. Club Bull. 78: 153-160.

Lists and discussions of the nonarborescent plants found on plots in 16 stands. Occurrence of 124 species or varieties of shrubs, vines, herbs, ferns, liverworts, mosses, and lichens is listed by type of stand, size of overstory trees, and past use of area. Pitch pine is mentioned as occurring in some stands of mixed composition — along with Atlantic white-cedar and swamp hardwoods.

299. Little, S., and E. B. Moore.

1949. **The ecological role of prescribed burns in the pine-oak forests of southern New Jersey.** Ecol. 30: 223-233, illus.

On upland sites forest succession is from pitch or shortleaf pine stands on old-field sites to a hardwood forest dominated by low-value oaks. The effect of wildfires on stand composition is briefly described, and data are given to show the effect of prescribed winter fires on pine and hardwood reproduction. The prescribed fires favor herbaceous plants over shrubs, and certain types of cutting increase the effectiveness of prescribed burns on stand composition.

300. Littlefield, E. W.

1952. **The pitch pine is dead — long live the white pine!** N. Y. State Conserv. 7(2): 24-25, illus.

In New York pitch pine is common on Long Island, on sandy plains between Albany and Lake George, in an area south of Plattsburg, and in the Oneida Lake Section. White pines frequently become established under pitch pine stands either naturally or through planting. The author recommends conversion to white pine by planting where needed and by release of natural or planted seedlings.

301. McCormick, Jack.

1955. **A vegetation inventory of two watersheds in the New Jersey Pine Barrens.** Diss. Abstr. 15: 1707-1708.

Quantitative description of vegetation on two areas in Lebanon State Forest, Burlington and Ocean Counties. Basal area, density, and cover measurements are given for all tree species, including pitch pine, which is predominant.

302. McIntyre, Arthur C.

1932. **The scrub oak type in Pennsylvania.** Pa. Forest Leaves 23: 74-77.

In Pennsylvania the scrub oak type covers over 2 million acres.

The cause of this type, its place in succession, its composition and conversion are described. Pitch pine is mentioned as one of the most desirable associates.

303. Moore, Barrington.

1917. **Some factors influencing the reproduction of red spruce, balsam fir, and white pine.** J. Forestry 15: 827-853, illus.

The pitch-pine association on Mt. Desert Island, Maine, is usually pure pitch pine, but frequently contains red pine or red and white pines. Other associated species are mentioned. The type occupies rocky, dry sites and granite ledges above the sea. Pitch pines usually reach only 15 to 20 feet in height and 6 to 10 inches d.b.h., and are of no commercial value. Most stands are composed of even-aged groups and on better sites form a pioneer type.

304. Moore, Barrington, and Norman Taylor.

1927. **Vegetation of Mount Desert Island, Maine, and its environment.** Brooklyn Bot. Gard. Mem. 3: 1-151, illus.

Stands composed of 80 percent or more of pitch pine, with associated red pine, white pine, red oak, red spruce, balsam fir, and red maple, grow on rocky, barren southfacing or level sites. Associated species of herbs and shrubs are listed, and soil and weather data from a pitch pine stand are presented. Evaporation and soil temperatures were higher than in any other forest type. The pitch pine type may be a physiographic climax, although usually early successional.

305. Nicholas, Herbert M.

1925. **What trees are replacing our chestnut.** Pa. Forest Leaves 20: 44-45.

Pitch pine is common in the new growth replacing chestnut, especially on ridges and slopes, but also in the valleys of Michaux State Forest, Pa.

306. Nichols, George E.

1914. **The vegetation of Connecticut. III. Plant societies on uplands.** Torreya 14: 167-194, illus.

On Connecticut sand plains the first tree species to appear are red cedar, gray birch, and pitch pine, either alone or in mixture. Oak and hickory succeed pitch pine, although in one stand near Farmington succession is being retarded by fire.

307. Niering, William A.

1953. **The past and present vegetation of High Point State Park, New Jersey.** Ecol. Monogr. 23: 127-148, illus.

Pitch pine is common in two communities: the pine-scrub (bear) oak on very thin soil with rocky outcrops, and the pine-oak found on some hilltops. On most sites the former is relatively stable because of rocky outcrops and frequent fires, but in the pine-oak community oaks are replacing pitch pines.

308. Ogden, J. Gordon, III.

1961. **Forest history of Martha's Vineyard, Massachusetts.**

I. Modern and pre-Colonial forests. Amer. Midland Natur. 66: 417-430, illus.

Pitch pine forms pure stands on old fields, but these are replaced by oaks. The original forests probably contained same species found today, but the trees were larger.

309. Olmstead, Charles E.

1937. **Vegetation of certain sand plains of Connecticut.** Bot. Gaz. 99: 209-300, illus.

On coarse sandy terraces in southern Connecticut there are three subseres leading to a xerophytic oak edaphic climax. Forests of pitch pine and associated oaks are mainly successional stages following the *Andropogon-Cladonia* association.

310. Olmstead, Charles E.

1956. **The North Haven sand plains.** Conn. Arboretum Bull. 9: 15-18, illus.

Old fields occupied by broomsedge have been invaded by pitch pine, which forms forests or savanna-like stands. Seed trees are 85 to 100 years old.

311. Parker, Dorothy.

1945. **Plant succession at Long Pond, Long Island, New York.** Butler Univ. Bot. Stud. 7: 74-88, illus.

Pitch pine is the dominant species of the Pinetum and is invading earlier seral stages. Species of associated trees, shrubs, and herbs are mentioned.

312. Reiners, W. A.

1967. **Relationships between vegetational strata in the pine barrens of central Long Island, New York.** Torrey Bot. Club Bull. 94: 87-99, illus.

In 9 of 15 stands studied, pitch pine was dominant in terms of basal area, and it was also present in 5 of the other stands. Scrub oak (*Quercus ilicifolia*) had the highest (although variable) cover in pine-dominated stands. Pine domination is favored by succession from mineral soil and is maintained by repeated burning.

313. Roberts, Edith Adelaide, and Helen Wilkinson Reynolds.

1938. **The role of plant life in the history of Dutchess County.** 44 pp., illus. Lansing-Broas Printing Co., Inc., Poughkeepsie, N. Y.

The pine association, including pitch, white, and red pines, replaces gray birch on old fields and is succeeded by the oak-hickory association. Pitch pine reaches 80 feet in height and 2 to 3 feet in diameter. Associated species of the pine association are listed. Maps show locations of pine stands and old pitch pines in this New York county.

314. Sampson, Homer C.

1927. **The primary plant associations of Ohio.** Ohio J. Sci. 27: 301-309.

Pitch pine is mentioned as occurring in southeastern Ohio in a "cliff association."

315. Saunders, C. F.

1900. **New Jersey Pine Barrens in July.** Plant World 3: 1-4, illus.

The author describes vegetation seen on an 1899 trip — pitch pines 2 to 3 feet tall in the East Plains, associated bear and blackjack oaks, mountain-laurel, bearberry, arbutus, pyxie-moss, sand-myrtle, crowberry, hudsonia, and others.

316. Shreve, Forrest, M. A. Chrysler, Frederick H. Blodgett, and F. W. Besley.

1910. **The plant life of Maryland.** Md. Weather Serv. Spec. Pub. 533 pp., illus.

The authors describe the vegetation in different sections of Maryland. Pitch pine is mentioned as occurring in various places, especially on sandy soils. However, it is rare on the Eastern Shore and also on the Western Shore except on sandy soils. Pitch pine occurs frequently in the Midland and Mountain Zones, but usually with Virginia pine or hardwoods. Associated plants are listed.

317. Society of American Foresters, Committee of the Southern Appalachian Section.

1926. **A forest type classification for the southern Appalachian Mountains and the adjacent plateau and Coastal Plain regions.** J. Forestry 24: 673-684.

The pitch pine-mountain pine type occurs in pure stands of one or both species, but usually with black, scarlet, and chestnut oaks and other hardwoods. It occupies dry flats, slopes, and ridges from 2,000 to 5,000 feet elevation in the Appalachian and Cumberland Mountains.

318. Stephenson, S. N.

1965. **Vegetation change in the Pine Barrens of New Jersey.** Torrey Bot. Club Bull. 92: 102-114, illus.

Results of a resurvey of 104 permanent sample units in Lebanon State Forest. Between 1954 and 1962 basal area increased, mostly in the early successional communities—little or no change occurred in older stands. Total number of stems decreased among tree species, as did the shrub cover—possibly because of drought. Pitch pine was the major component of basal area in two types.

319. Stern, William L., and Murray F. Buell.

1951. **Life-form spectra of New Jersey Pine Barrens forest and Minnesota jack pine forest.** Torrey Bot. Club Bull. 78: 61-65.

When a pitch pine-shortleaf pine stand in southern New Jersey is compared to a Minnesota jack pine stand, the latter has more protected life-forms, apparently because of a more severe climate.

320. Weiss, Harry B., and Erdman West.

1924. **Insects and plants of a dry woods in the Pine Barrens of New Jersey.** Ecol. 5: 241-253, illus.

The authors studied a 10-acre wooded area near Lakehurst, in which pitch pine predominated, and a 4-acre open area nearby.

Associated plants are described, as are the insects found under various conditions in both areas.

321. Whittaker, R. H.
1956. **Vegetation of the Great Smoky Mountains.** Ecol. Monogr. 26: 1-80, illus.

Pitch pine occurs from lowest elevations to about 4,500 feet, but the type is usually found on open south and southwest slopes and on some ridges between 2,200 and 3,200 feet. Associated tree and other plant species are mentioned. Pine stands are considered an edaphic climax favored by fire.

321a. Whittaker, R. H., and G. M. Woodwell.
1969. **Structure, production and diversity of the oak-pine forest at Brookhaven, New York.** J. Ecol. 57: 155-174, illus.

The Brookhaven forest is composed of small oaks and pitch pine with an open canopy, of 88-percent tree coverage and leaf area ratio of 3.4, admitting 13 percent of incident sunlight so vacciniaceous shrubs form well-developed stratum (78-percent coverage). Data are given for (1) biomass above ground and above-and-below ground, (2) net annual production, and (3) efficiency of net and gross production. The limited number of species mentioned permits observations on niche differentiation among trees, shrubs, and herbs.

322. Williams, Ruby M., and H. J. Oosting.
1944. **The vegetation of Pilot Mountain, North Carolina: a community analysis.** Torrey Bot. Club Bull. 71: 23-45, illus.

Although Pilot Mountain is in the Piedmont, most of the vegetation is similar to that of the southern Appalachians, probably because of the sandy soil and elevation. Pitch pine occurs in all communities, but with chestnut oak dominates the stands on the western half of the mountain and on the higher southern slopes. The chestnut oak-pitch pine community is considered preclimax to the oak-hickory association and is favored by the thin rocky soil.

323. Woods, Frank W., and Royal E. Shanks.
1957. **Replacement of chestnut in the Great Smoky Mountains of Tennessee and North Carolina.** J. Forestry 55: 847.

Pitch pine formed 2 percent of 5,046 replacements in 2,569 openings in 79 stands investigated.

324. Zube, Ervin H., and Carl A. Carlozzi (editors).
1967(?). **Selected resources of the Island of Nantucket: an inventory and interpretation.** Univ. Mass. Coop. Ext. Serv. Pub. 4. 135 pp., illus.

The Island was generally wooded when the first colonists arrived, but then 90 percent of it was cleared. Pitch pine has been planted, reaches 60 feet in height, but suffers from wind exposure, especially on the edges of the stands. Natural reproduction of pitch pine invades the heath, and pitch pine is present in the oak scrub type.

SILVICULTURE & MANAGEMENT

General

325. Baker, Willis M.

1925. **Forestry for profit.** N. J. Dep. Conserv. and Develop. 88 pp., illus.

A general description of New Jersey forests, forestry problems, and State activities in forestry; and a discussion of the silviculture and management of common forest types. For pitch and shortleaf pines, thinnings are recommended at 25 to 30 years, clearcuttings or seed-tree cuttings at 40 to 60 years, and release from hardwood sprouts. The need for favorable seedbeds, the growth of pine sprouts, yields, and logging and planting techniques are described. Planting of pitch pine is recommended only for poor dry soils. Properties and uses of pitch pine wood are also described, and volume tables are given.

326. Baker, Willis M.

1936. **Comments on timber stand improvement in the Central States.** USDA Forest Serv. Cent. States Forest Exp. Sta. Sta. Note 30. 6 pp.

Shortleaf, Virginia, and pitch pines are associates of upland oaks on dry sites in unglaciated sections. Many present dry-site oak stands should be converted to pine by cutting at the time of a pine seed crop or, if natural reproduction cannot be obtained, by planting.

327. Belyea, Harold Cahill.

1922. **A suggestion for forest regions and forest types as a basis of management in New York State.** J. Forestry 20: 854-868, illus.

The pitch pine type occurs on Long Island and on dry soils of the Mohawk and Hudson Sand Plains. Replacement of this species with white, red, or Scotch pines is recommended.

328. Bentley, John, Jr.

1905. **Pitch pine in Pike County, Pennsylvania.** Forestry Quart. 3: 1-17, illus.

A discussion of distribution and growth of pitch pine on different sites and in different stand types. Cone crops, seed distribution, and effects of fires are described. Volume tables are given in cubic feet, board feet, and cords.

329. Cantlon, John E., and Murray F. Buell.

1952. **Controlled burning — its broader ecological aspects.** Bartonia 26: 48-52.

Possible effects of controlled burning on water supplies, shrubs, insects, deer, and other wildlife in the New Jersey Pine Region are discussed.

330. Cranmer, Carl B.

1952. **Future of the Pine Barrens.** Bartonia 26: 53-60.

Quotes early descriptions of forests in the New Jersey Pine Region; and describes the industrial use, fires, recreation, protection from wildfires, probable land use, possible timber yields, and benefits from prescribed burning. Recommends formulation of a land-use policy.

331. Dana, Samuel T.

1930. **Timber growing and logging practice in the Northeast.** U. S. Dep. Agr. Tech. Bull. 166. 112 pp., illus.

Briefly describes forests in the pine-and-oak region of Cape Cod, Long Island, and southern New Jersey, and suggests methods of harvest cutting, slash disposal, cleaning, and thinning. Recommends favoring shortleaf pine over pitch pine. The latter is mentioned as common on poor sites in the oak type.

332. Gifford, John.

1900. **The forestal conditions and silvicultural prospects of the Coastal Plain of New Jersey, with remarks in reference to other regions and kindred subjects.** N. J. State Geol. Annu. Rep. 1899: 235-318, illus.

Describes forests of the New Jersey Coastal Plain, including Plains growth (its area and the reasons for it), other Pine Barren types, effects of fires, dune forests and dune stabilization, industrial use of Pine Barren forests, and fire protection. Discusses possible role of various cutting systems and techniques to use in direct seeding. Recommends favoring shortleaf over pitch pine.

333. Illick, Joseph S., and John E. Aughanbaugh.

1930. **Pitch pine in Pennsylvania.** Pa. Dep. Forests and Waters Res. Bull. 2. 108 pp., illus.

A comprehensive bulletin: it includes common names, identifying and silvical characteristics (including growth habits, intolerance of shade, seed production, sprouting, and fire resistance), range and distribution, form and maximum size, common associates, silviculture and utilization of pitch pine, and damage by snow, ice, deer, insects, and diseases. Nursery practices, extent and success of plantings, growth of stands and yield are described; and recommendations are made for shelterwood cuttings or clearcuttings and for release from competing hardwoods. Volume tables and yield tables by age and site class are included, as are descriptions of properties and uses of pitch pine wood.

334. Little, S.

1952. **Silvicultural objectives and methods on upland sites in the New Jersey Pine Region.** Bartonia 26: 44-47.

Composition of present stands and factors affecting it and succession are described. Present annual growth of pine-scrub oak stands is about 1/10 cord per acre, of oak-pine stands about 1/4 cord, and the potential in seedling-pine stands about 1 cord. Discusses role of planting, site preparation with machinery or prescribed winter fires, need for release of pine reproduction, and desirable amount of area in one age class.

335. Moore, E. B.
1939. **Forest management in New Jersey.** N. J. Dep. Conserv. and Develop. 55 pp., illus.

Describes physiographic provinces of New Jersey, their forests and land uses, conservation problems and forestry program, forest management, and silviculture. Includes description of Plains stands and discusses the cause of such growth, original and current stand conditions in the Pine Region, planting of pitch pine and other species to increase proportion of conifers, and their release. Data given show how an increasing proportion of pine increases the yield of oak-pine stands.

336. Moore, E. B.
1940. **Forest and wildlife management in the South Jersey Pine Barrens.** J. Forestry 38: 27-30, illus.

Briefly describes the Pine Barrens, relative yields of oak and pine stands, and conversion to pine through cutting oak and planting pine. Wildlife-management measures include preparation of 0.5- to 2-acre clearings connected by cleared 25-foot lanes, both of which are sown to native herbaceous plants. Between outer lanes and roads are prescribe-burned firebreaks, and interior stands are thinned to favor pine over oak.

337. Toumey, James W., and Clarence F. Korstian.
1942. **Seeding and planting in the practice of forestry.** Ed. 3, 520 pp., illus. John Wiley and Sons, Inc., New York.

Mentions early plantings of pitch pine, and presents data on the opening of cones, number of seeds per pound, yield of seed per bushel of cones, seed purity and viability, seed stratification, germinating period in seed testing, recommended seedling densities and depth of soil coverings in nursuries. Discusses use of pitch pine in stabilizing New England dunes.

Seed Collection, Storage, and Treatment

338. Barton, Lela V.
1930. **Hastening the germination of some coniferous seeds.** Amer. J. Bot. 17: 88-115, illus.

In the seed lot tested, germination of seeds stratified for 1 month at 5°C. was 87 percent after 12 days and 95 percent after 18 days; germination of untreated seeds was only 3 percent after 12 days and 33 percent after 50 days. Germination was also increased by stratification for 1 to 3 months at 0° or 10°C.

339. Blaydes, David F.
1967. **Studies on the germination of seed of *Pinus rigida.*** W. Va. Acad. Sci. Proc. 38: 68.

In several tests both white and red light greatly stimulated germination over that in dark controls, whereas far-red light greatly reduced it.

340. Haasis, Ferdinand W.

1928. **Germinative energy of lots of coniferous-tree seed, as related to incubation temperature and to duration of incubation.** Plant Physiol. 3: 365-412, illus.

For one lot of pitch pine seed, optimal temperature for the shortest incubation period (6 to 7 hours) was 46° C.; optimum for 4 to 14 days was 23 to 33°. In five lots tested, one lot had a double optimum for germination; but two other lots weakly indicated a double optimum and in two others no evidence of this appeared. Temperatures tested varied from 8° to 57° C.

341. Heit, C. E.

1958. **The effect of light and temperature on germination of certain hard pines and suggested methods for laboratory testing.** Assoc. Offic. Seed Anal. Proc. 48: 111-117, illus.

For testing pitch pine seed, the author recommends blotters as a substrate, temperatures of 20 to 30° C., and use of artificial light if needed during an 8-hour high-temperature period. First count should be made at 7 to 10 days, final count at 14 days.

342. Heit, C. E.

1961. **Shorter germination test durations for tree seeds.** Int. Seed Testing Assoc. Proc. 26(3): 428-436.

For pitch pine the author recommends placing seeds on top of blotters at 20 to 30° C., alternating temperature with artificial light during 8-hour high-temperature period, and germination period of 6 to 10 days. Prechilling is unnecessary.

343. Heit, C. E.

1967. **Propagation from seed. Part 10: Storage method for conifer seeds.** Amer. Nurseryman 126(8): 14-15, 38, 40, 42-44, 46, 48, 50, 52, 54, illus.

Store pine seeds at moisture contents of 5 to 8 percent under sealed refrigeration (34 to 38° F.). Pitch pine seed will keep for 1 or 2 years without cold storage if moisture content is less than 10 percent.

344. Heit, C. E.

1968. **Thirty-five years' testing of tree and shrub seed.** J. Forestry 66: 632-634.

Pitch pine seed requires only artificial light for rapid and complete germination within 7 to 12 days in laboratory tests.

345. Heit, C. E., and E. J. Eliason.

1940. **Coniferous tree seed testing and factors affecting germination and seed quality.** N. Y. State Agr. Exp. Sta. Tech. Bull. 255. 45 pp., illus. Geneva, N. Y.

Methods of seed testing and results with different species are described. In 10 lots of pitch pine seed, 79 percent of the seeds germinated, and 9 percent were empty. Most lots germinated rapidly. Germination of only one lot benefited from prechilling.

346. Perry, George S., and C. A. Coover.

1933. **Seed source and quality.** J. Forestry 31: 19-25.

Larger cones of pitch pine yielded heavier and more viable seeds. Cone size varied among trees, but was rather uniform for a tree. Early-opening cones tended to be larger, but had fewer viable seeds than other cones. Differences were small.

347. Pettis, C. R.

1909. **How to grow and plant conifers in the Northeastern States.** U. S. Dep. Agr., Forest Serv. Bull. 76. 36 pp., illus.

Besides describing general procedures for seed collection and extraction, for nursing and planting practices, and for seeding, the author mentions that pitch pine cones may be collected during September and October and that seeds are easily extracted, with large yields. Average number of seeds is 50,000, and usual germination is 65 to 85 percent.

348. Rules Committee, Association of Official Seed Analysts.

1965. **Rules for testing seeds.** Assoc. Offic. Seed Anal. Proc. 54 (2):1-112.

A sample for germination purposes shall consist of at least 600 seeds. Gives 20 grams as minimum weight for purity analysis of pitch pine seed, number of seeds per gram or ounce, and methods of testing germination of pitch pine seed (following Heit 1958).

349. Toumey, James W., and Clark L. Stevens.

1928. **The testing of coniferous tree seeds at the School of Forestry, Yale University, 1909-1926.** Yale Univ. School Forestry Bull. 21. 46 pp., illus.

On the basis of 11 samples, pitch pine seeds varied between 35,552 to 71,616 per pound, germinated at the rate of 49 to 93 percent and in some samples as high as 49 percent within 15 days, and in commercial lots were about 99 percent pure. Either spring or fall sowing gave successful germination in nurseries.

350. U. S. Forest Service.

1948. **Woody-plant seed manual.** U. S. Dep. Agr. Misc. Pub. 654. 416 pp., illus.

For many species of pine, including pitch pine, this manual lists time of flowering, cone ripening, and seed dispersal; seed-bearing age; frequency of seed crops; number of closed cones per bushel; yield of seed per bushel of cones; number of seeds per pound; purity and soundness of seed; recommended storage and stratification methods for seed; and conditions to use in germination tests. Briefly describes nursery practices, and important sources of nursery injuries and their control.

Nursery Practice (including vegetative propagation)

351. Auten, John T.

1945. **Response of shortleaf and pitch pines to soil amendments and fertilizers in newly established nurseries in the Central States.** J. Agr. Res. 70: 405-426, illus.

Peat used to correct alkalinity beneficially affected height and density of seedlings. Phosphoric acid, superphosphate, and iron phosphate increased height growth, root length, and root weight. Seedling density varied inversely with quantity of phosphorus but was increased by potassium sulfate. Potassium did not stimulate height growth, and nitrogen applied at seeding time lowered seedling density.

352. Choi, S. K.

1966. **Studies on the plus tree grafting (conifer).** Korean Min. Agr. Forestry Office Rural Develop. Res. Rep. 9(2): 97-108, illus.

Grafting experiments included pitch pine and four other species. The author studied effect of compatibility between stock and scion, length of storage period for scion material, type and status of scion, date of grafting, and bagging upon grafting success in field and greenhouse.

353. Heit, C.E.

1967. **Propagation from seed. Part 9: Fall sowing of conifer seeds.** Amer. Nurseryman 126(6): 10-11, 56, 60, 62, 64-69, illus.

Pitch pine seeds may be slightly dormant, and their germination will benefit from fall sowing.

354. Hyun, S. K.

1967. **Physiological differences among trees with respect to rooting.** Int. Union Forestry Res. Organ. 14th Cong. 3: 168-190, illus.

Though pitch pine is relatively difficult to root, differences among tested trees showed high survival and good rootability of cuttings from some trees, low survival and rootability from others. High C/N ratio, low nitrogen level, and relative amounts of root-promoting substances, such as indoleacetic acid, are associated with rootability of pitch pine cuttings.

355. Johnson, Albert G.

1947. **Some effects of "2,4-D," on pines.** J. Forestry 45: 288-289.

Application of 2,4-D in a nursery caused some mortality and damage to pitch pine, but more among current-year seedlings than among those in their second season.

356. Mergen, François.

1954. **Heteroplastic micrografting of slash pine.** USDA Forest Serv. SE. Forest Exp. Sta., Sta. Paper 47. 17 pp., illus. Asheville, N. C.

A slash pine (*Pinus elliottii*) scion 1.5 months old was grafted onto a 4-month-old pitch pine and a year later was 5.6 inches tall.

357. Retan, George A.

1918. **Nursery practice in Pennsylvania.** J. Forestry 16: 761-769.

Describes nursery practices then in use. Application of acid soil decreased damping-off and increased survival of pitch pine seedlings from 62 percent in check beds to 92 percent in treated beds.

358. Santamour, Frank S., Jr.

1965. **Rooting of pitch pine stump sprouts.** Tree Planters' Notes 70: 7-8.

Near Laurel, Md., a stump of a 29-year-old tree produced 108 sprouts 4 to 12 inches long at end of first (1961) growing season. Of sprouts collected in September, 66 percent of those treated with Hormodin No. 3 rooted, but none of the controls. None of the sprouts collected the following January rooted.

359. Yim, Kyong Bin.

1962. **Physiological studies on rooting of pitch pine *(Pinus rigida* Mill.) cuttings.** Korean Inst. Forest Genet. Res. Rep. 2: 22-56, illus.

Rooting success varied with crown position, age of parent tree, season of collection, rooting medium, length of cutting, presence or absence of flower primordia, and treatment with synthetic plant hormones.

Seeding and Planting

360. Adams, W. R., and G. L. Chapman.

1942. **Competition in some coniferous plantations.** Vt. Agr. Exp. Sta. Bull. 489. 26 pp., illus.

Results 28 years after planting 5 species of pine in the Champlain Valley sand plain at spacings of 2 to 8 feet. Pitch pine grew more slowly than jack, red, white, or Scotch pine. Pitch pines at 28 years had mean heights of only 17 to 19 feet. Diameter and height of pitch pines increased with increased spacing, while the number of living trees and basal area per acre declined (from 8,603 trees per acre and 196.7 square feet in the 2-foot spacing).

361. Allen, John C.

1950. **Pine planting tests in the Copper Basin.** J. Tenn. Acad. Sci. 25: 199-216, illus.

In the 23,000-acre man-caused desert of the Tennessee Copper Basin, soil erosion, exposure to climatic extremes, and occasional injurious concentrations of sulfur dioxide present severe difficulties in erosion-control plantings. Of the four native pines, pitch pine has had the slowest height growth during the first 3 to 7 years—0.6 foot per year; loblolly pine has had the most—1.2 feet. However, pitch pine has had the best survival, and one excavated tree per species showed that pitch pine had the most extensive root development. Mixed plantings of loblolly and pitch pines are recommended.

362. Altpeter, L. Stanford.

1941. **Reforestation of sandblows in northern Vermont.** J. Forestry 39: 705-709, illus.

Wind erosion may be severe on cleared lands where soils are water-deposited sands of glacial origin. Stabilization measures are described. Excellent survival and satisfactory growth of planted pitch pines and other species are mentioned, but no data are given.

363. Boyce, Stephen G., and Robert W. Merz.
1959. **Tree species recommended for strip-mine plantations in western Kentucky.** USDA Forest Serv. Cent. States Forest Exp. Sta. Tech. Paper 160. 12 pp., illus.

Of the pines planted on moderately acid to acid areas, loblolly and pitch pines had the best form. At 10 years pitch pines were shorter than loblolly pines, but slightly taller than Virginia or shortleaf pines. However, the latter two had suffered more tip-moth damage.

364. Boyce, Stephen G., and David J. Neebe.
1959. **Trees for planting on strip-mined land in Illinois.** USDA Forest Serv. Cent. States Forest Exp. Sta. Tech. Paper 164. 33 pp., illus.

Survival of pitch pines was considered satisfactory on all sites except poorly drained ones, but the trees were so crooked and limby that pitch pine was rated the least desirable of the pines. Pitch pines were damaged by tip moths and ice.

365. Bramble, William C., and Maurice K. Goddard.
1942. **Effect of animal coaction and seedbed condition on regeneration of pitch pine in the barrens of central Pennsylvania.** Ecol. 23: 330-335, illus.

The study included aspen, scrub oak, and grass communities and five seedbed treatments of seed spots. In aspen and scrub oak, unfavorable seedbeds—plus destruction of seed by birds or small mammals—prevented pitch pine establishment. In the grass community, covering the seeds with soil or sod, but without protection from birds or mammals, gave successful germination, although only low survival.

366. Bramble, William C., Henry H. Chisman, and Glenn H. Deitschman.
1948. **Research on reforestation of spoil banks in Pennsylvania.** Pa. State Coll. Forest School Res. Paper 10. 6 pp.

Pitch pine was found on acid shale and sandstone banks with pH 3.5 to 4.2. Growth was fairly good; on one bank trees were 36 feet tall and nearly 6 inches d.b.h. after 22 years. Poor survival of recent plantings was attributed to poor planting stock.

367. Bramble, W. C:, and H. N. Cope.
1947. **Reforestation with certain trees succeeds on droughty, shallow soils.** Pa. Agr. Exp. Sta. Bull. 480, Suppl. 2: 1-2, illus.

In the Stone Valley Experimental Forest in Huntingdon County, several species were tried for reforesting abandoned fields. Deer browsing was more severe on the planted pitch pines than on other species and caused high mortality and stunting.

368. Brouse, E. F.
1930. **Planted forest trees grow and how.** Pa. Forest Leaves 22: 179-181.

On the basis of plantation studies, pitch pine outgrew other species at 10 years, and at 15 years was second to Scotch pine. Average heights of pitch pine in 25 Pennsylvania plantations were 3.4 feet at 5 years, 8.2 at 10 years, and 13.2 feet at 15 years.

369. Brown, James H., Jr., and Walter P. Gould.
1963. **Direct seeding of conifers in Rhode Island.** Tree Planters' Notes 61: 1-4.

On bulldozed strips, pitch pine seed treated with Arasan-75 and endrin was sown in the fall and spring at the rate of 2 pounds per acre (along with white pine and hemlock seed). After two growing seasons the fall-sown area had 9,428 pitch pine seedlings per acre; the spring-sown area had 6,000. Pitch pine seedlings outgrew white pine seedlings, some of the former being three to four times as tall as the white pine.

370. Brown, James H., Jr., and Walter P. Gould.
1965. **Direct seeding native conifers in Rhode Island.** Univ. Mass. Exp. Sta. Bull., Direct seeding in the Northeast—A symposium, Proc.: 73-75.

After five growing seasons in the study described above (*Brown and Gould 1963*), the fall-sown area had 9,430 pitch pines per acre; the spring-sown areas had 6,000. Seedlings from fall sowing were 31 inches tall, those from spring sowing 27 inches tall. Both lots were much taller than white pine seedlings (10 and 9 inches respectively).

371. Brown, R. M.
1928. **Survival and growth of trees planted in Rock Creek Arboretum, Washington, D. C.** J. Forestry 26: 94-104.

Planted pitch pines survived at the rate of 81 to 100 percent and over about a 9-year period had a mean annual height growth of 1.0 to 1.9 feet.

372. Buttrick, P. L.
1920. **American trees for forest planting in France.** J. Forestry 18: 815-822.

Pitch pine is suggested for dune stabilization in northern France, a section where maritime pine is not hardy.

373. Chapman, A. G.
1937. **An ecological basis for reforestation of submarginal lands in the central hardwood region.** Ecol. 18: 93-105, illus.

The range of pitch pine in southern Ohio and Kentucky is limited to residual sandstone soils and cherty mantle. The author recommends yellow pines for poorer, drier slopes. In northern states of the region, planted pitch pines are usually 1-1 transplants; farther south 1-0 seedlings are planted.

374. Chapman, A. G., and R. D. Lane.
1951. **Effects of some cover types on interplanted forest tree species.** USDA Forest Serv. Cent. States Forest Exp. Sta. Tech. Paper 125. 15 pp., illus.

Planted pitch pines or other pines can serve in preparing sites for later interplanted hardwoods, but form a less desirable nurse crop than black locust. Within 13 years all pitch pines planted in mixture with black locust were overtopped and had died.

375. Clark, F. Bryan.
1954. **Forest planting on strip-mined land in Kansas, Missouri, and Oklahoma.** USDA Forest Serv. Cent. States Forest Exp. Sta. Tech. Paper 141. 33 pp., illus.

After 6 years, pitch pines planted as 1-0 stock on 12 sites had 0 to 78-percent survival and mean heights of 2.5 to 5.8 feet. Survival and growth were best on north and east slopes, least in bottoms. Amount of cover influenced first-year survival.

376. Committee on Site Classification, Northeastern Forest Soils Conference.
1961. **Planting sites in the Northeast.** USDA Forest Serv. NE. Forest Exp. Sta., Sta. Paper 157. 24 pp., illus. Upper Darby, Pa.

The committee described sites in broad terms, and recommended species for forest plantings on these sites in different areas of the Northeast. Pitch pine was recommended for some sections, usually on the more adverse sites (droughty to very poorly drained).

377. Curlin, James W.
1962. **Planted pitch pine responds to fertilization.** Tree Planters' Notes 55: 3-4.

In the Copper Basin of Tennessee, planted pitch pines survived far better (95 percent) than loblolly, shortleaf, or Virginia pines. Survival was not affected by fertilizer treatments, but over a 7-year period height growth was favored by single fertilizer treatments. Nitrogen increased early growth; phosphorus and potassium appeared to be largely responsible for long-term increase in height growth.

378. Davis, Grant, and Rex E. Melton.
1962. **Plantations on strip-mine banks can yield timber products.** Pa. State Forest School Res. Paper 29. 2 pp.

On strip-mine banks in Pennsylvania's bituminous coal region, plantations of pitch pine after 25 years contained larger trees and more volume than those of jack or table-mountain pine, but smaller trees and less volume than those of red, white, or Scotch pine.

379. Davis, Grant, and Rex. E. Melton.
1963. **Trees for graded strip-mine spoils.** Pa. State Forest School Res. Paper 32. 4 pp.

Performance of 15 species was rated on graded spoil banks of Pennsylvania's bituminous region. Plantations of pitch pine were classed as good in survival and height growth on the spoils of three coal seams, satisfactory on those of four other seams.

380. Deitschman, Glenn H., and Richard D. Lane.
1952. **Forest planting possibilities on Indiana coal-stripped lands.** USDA Forest Serv. Cent. States Forest Exp. Sta. Tech. Paper 131. 57 pp., illus.

Pitch pine is one of the species recommended for acid or calcareous sands in the Illinoian Glaciated Region. Data are for 4- or 5-year survival and height growth in experimental plantings that included pitch pine.

381. Diebold, C. H.

1940. **Strip planting for flood control.** J. Forestry 38: 810-812, illus.

Use of pitch pine is recommended in plantings for flood control in Pennsylvania. Pitch pine crowns close almost as soon as those of Scotch pine, and 2 to 4 years sooner than those of red or white pine. Pitch pine also develops a deeper humus layer (1½ to 2 inches deep after 15 years). Suggests arrangement of pitch pine and other species for flood control and timber production.

382. Emerson, George B.

1850. **A report on the trees and shrubs growing naturally in the forests of Massachusetts.** 547 pp. Charles C. Little and James Brown, Boston.

Pitch pine is commonly 40 to 50 feet tall and 1 to 2 feet in diameter at the base, but some trees reach heights of 100 feet or more and diameters of 4 or 5 feet. Its wood has been used in ship-building; for floors, water wheels, pumps, sills and framing of buildings, railroad ties, nail casks, and fuel. On old fields natural reproduction grows at the rate of an inch in diameter in 3 or 4 years for the first 25 years and then 1 inch in 5 or 6 years. Seedlings reach heights of 3 to 4 inches in the first year, are up to 2 feet tall in 3 years, and then may grow 2 or 3 feet a year on favorable sites. Pitch pine is resistant to salt spray and is recommended for dune plantings.

383. Finn, Raymond F.

1958. **Ten years of strip-mine forestation research in Ohio.** USDA Forest Serv. Cent. States Forest Exp. Sta. Tech. Paper 153. 38 pp., illus.

Pitch pine had better survival and growth when planted on silty-shale ungraded banks with pH 3.0 to 5.0 than on spoils of calcareous clay or limestone with a pH of 7.0.

384. Gibbs, J. A.

1948. **Growth of tree plantings for erosion control in the southeastern region.** Iowa State Coll. J. Sci. 22: 371-386, illus.

Pitch pine was one of the species planted for erosion control in the Southeast (Virginia and Kentucky southward). Though it and Virginia pine proved to be rugged on eroded sites in the northern part, both are recommended only in mixture with shortleaf or white pine.

385. Goldring, W.

1887. **Trees and shrubs. The American pitch pine *(Pinus rigida)*.** Gard. 31: 128, illus.

A brief description of the natural range of pitch pine and its distinguishing characteristics. The species is recommended for ornamental plantings on severe sites in England. Early plantings made as much as 130 years ago are mentioned.

386. Grisez, Ted J.
1968. **Growth and development of older plantations in northwestern Pennsylvania.** USDA Forest Serv. Res. Paper NE-104. 40 pp., illus. NE. Forest Exp. Sta., Upper Darby, Pa.

A follow-up on Hetzel's study, it includes data on three pitch pine plantations 40 to 45 years old. The author recommends other species and not pitch pine.

387. Hart, George E., and William R. Byrnes.
1959. **Performance of trees planted on coal-stripped lands in the bituminous region of Pennsylvania.** Pa. State Forest School Res. Paper 28. 2 pp.

Pitch pine was rated as intermediate in site requirements, and is adapted to all sites except those with extreme slopes or with severe wind exposure. Pitch pines 10 years after planting had a survival of 36 percent and were 8.2 feet tall. Pitch pine was not recommended where pine sawflies are common.

388. Hart, George, and William R. Byrnes.
1960. **Trees for strip-mined lands.** USDA Forest Serv. NE. Forest Exp. Sta., Sta. Paper 136. 36 pp., illus. Upper Darby, Pa.

For planting on strip-mined lands of Pennsylvania's bituminous region, pitch pine was rated only as fair. This conclusion was based on 10-year survival and height and diameter growth. In several plantings pitch pines were stunted, possibly because of severe winds or partly because of seed origins.

389. Hetzel, J. E.
1941. **Forest plantations in northwestern Pennsylvania.** USDA Forest Serv. Allegheny Forest Exp. Sta. Occas. Paper 3. 6 pp., illus.

Data on survival, height, and diameter of four plantations 19 to 24 years from seed. Pitch pine was rated about medium among conifers in growth and form, but on medium sites was dropped to seventh place (just ahead of white pine) in relative performance of conifers.

390. Illick, J. S.
1919. **Preliminary report of some forest experiments in Pennsylvania.** J. Forestry 17: 297-311, illus.

About 1.5 million pitch pines had been planted on State lands in Pennsylvania. For converting low-value stands, the author recommended planting 600 to 1,000 2-0 seedlings per acre under existing growth, and beginning release cuttings 2 or 3 years after planting.

391. Keller, John W.
1925. **Free distribution of forest trees in Pennsylvania.** J. Forestry 23: 896-904.

In a survey of plantations established between 1915 and 1922, 89 percent of 71,800 planted pitch pines were still alive. Where pitch pines older than 2 years were used, survival rate was lower.

392. Leach, Walter.

1935. **Fall planting of conifers.** Pa. Forest Leaves 25: 75, 79.

Planting in October and November may be successful on Pennsylvania sites not subject to frost heaving: in one test pitch pines had 82 to 85 percent survival 1 year after fall planting.

393. Limstrom, G. A.

1960. **Forestation of strip-mined land in the Central States.** U. S. Dep. Agr. Agr. Handb. 166. 74 pp., illus.

Conditions suited to pitch pine are described, but pitch pine is not recommended for large-scale planting.

394. Limstrom, G. A., and G. H. Deitschman.

1951. **Reclaiming Illinois strip coal lands by forest planting.** Univ. Ill. Agr. Exp. Sta. Bull. 547: 201-250, illus.

In Saline and St. Clair Counties, survival of 8-year-old plantings of pitch pine ranged from 49 to 98 percent and height growth averaged 1.5 feet per year. Second-year survival of plantings in several counties varied from 3 to 84 percent. Counties and conditions where pitch pine is one of the recommended species for planting are given.

395. Little, S.

1965. **Direct seeding in southern New Jersey and the Pennsylvania Poconos.** Univ. Mass. Exp. Sta. Bull., Direct Seeding in the Northeast—A Symposium, Proc.: 64-68.

Describes procedures necessary for direct-seeding pitch pine successfully on moderately to excessively drained soils of southern New Jersey. Drought severely limited success in 10 percent of the years on all upland sites, and more often on the driest sites.

396. Little, S., C. B. Cranmer, and H. A. Somes.

1958. **Direct seeding of pitch pine in southern New Jersey.** USDA Forest Serv. NE. Forest Exp. Sta., Sta. Paper 111. 14 pp., illus. Upper Darby, Pa.

Tests included seed spots and broadcast sowing, disking and prescribed burning for seedbed preparation, brush-hogging to reduce competition and cover broadcast-sown seed, on different well or imperfectly drained soils. Results showed that for adequate amounts of pine reproduction, these conditions need to be met: (1) sufficient sound seed, sown preferably in January or February; (2) a favorable seedbed; (3) light cover of soil or debris over seed; (4) sufficient protection from rodents and birds; and (5) favorable weather for at least two growing seasons.

397. Ludwig, Walter D.

1923. **Reforestation by coal companies in southwestern Pennsylvania.** J. Forestry 21: 492-496.

To meet the needs of coal companies and to make brush lands and abandoned farm lands productive, planting of pitch pine or other conifers is recommended.

398. Ludwig, Walter D.

1924. **Reforestation progress and costs in southwestern Pennsylvania.** J. Forestry 22: 184-189.

Pitch pines planted in 1916 as 2-0 stock had current annual height growth of 1.6 feet, average annual growth of 0.85 feet. Those 4 years old when planted in 1920 had growth values of 1.6 and 0.6 feet, respectively. Values based on 66 and 47 trees.

399. McConkey, Thomas W.

1964. **Direct seeding of pine and spruce in southwestern Maine.** USDA Forest Serv. Res. Paper NE-24. 13 pp., illus. NE. Forest Exp. Sta., Upper Darby, Pa.

Effects of seedbed preparation and shade on germination and first-year establishment of five coniferous species were studied. Pitch pine germination and establishment were best on scalped, shaded spots sown in the spring, although the difference between spring and fall sowing was small. Pitch pine seemed to have less exacting moisture requirements than red or white pines.

400. McConkey, T. W.

1965. **Intolerant species and direct seeding.** Univ. Mass. Exp. Sta. Bull., Direct Seeding in the Northeast—A Symposium, Proc.: 97-98.

Direct seeding is usually more successful with intolerant species than with tolerant species, because the former have early and rapid germination of seed, the growth habit (as in pitch pine) may protect seedlings from heat injury, and these intolerant species are better adapted to sites commonly selected for direct seeding.

401. McLintock, Thomas F.

1940. **Effects of ground preparation on survival and growth of planted pine and black locust.** USDA Forest Serv. Cent. States Forest Exp. Sta. Tech. Note 23. 4 pp.

In Hocking County, Ohio, and in southern Illinois, plowing or furrowing before planting old-field sites increased the height growth of pitch pines, but by 0.6 foot or less during a 3- or 5-year period.

402. McLintock, Thomas F.

1942. **Stratification as a means of improving results of direct seeding of pines.** J. Forestry 40: 724-728.

Stratification of seed improved both germination and catch in direct seeding pitch pine. Effects were much more pronounced on northern slopes than on southern slopes.

403. McNamara, E. F., and Irvin C. Reigner.

1955. **Root competition slows growth of plantings on unprepared sites in scrub oak.** USDA Forest Serv. NE. Forest Exp. Sta. Forest Res. Note 54. 3 pp. Upper Darby, Pa.

In scrub oak on the Delaware-Lehigh Experimental Forest in Pennsylvania, pitch pines planted in 4-foot-wide bulldozed furrows were 4.2 feet tall, those in ammate-treated strips were 3.8

feet, and those in openings of unprepared sites were 2.4 feet tall after 5 years.

404. McQuilkin, W. E., Irvin C. Reigner, and Eugene McNamara. 1953. **Scrub oak conversion studies. *In* Forest and Water Research Project, Delaware-Lehigh Experimental Forest.** Pa. Dep. Forests and Waters Rep. 2: 1-7, illus.

The 1948 plantings of pitch pine did poorly because of poor stock. For 1950 plantings made in furrows 3 to 4 feet wide, pitch pine survival was 90 percent in 1952, and pitch pines were growing nearly as fast as jack pines. A desirable density of natural reproduction was obtained where bulldozers exposed mineral soil within 100 feet of seed trees.

405. McQuilkin, W. E., E. F. McNamara, and Irvin C. Reigner. 1955. **Scrub oak conversion studies. *In* Forest and Water Research Project, Delaware-Lehigh Experimental Forest.** Pa. Dep. Forests and Waters Rep. 3: 1-9, illus.

In the Poconos, planted pitch pines have been loosened by high winds. Pitch pines have grown better on prepared sites than when interplanted: on furrowed sites mean height was 4 feet after 5 years. Additional trials of direct seeding were failures. Excessive deer browsing has prevented adequate survival and growth of natural reproduction obtained by scarification near seed sources.

406. McQuilkin, W. E., and E. F. McNamara. 1961. **Scrub oak conversion. *In* Forest and Water Research Project, Delaware-Lehigh Experimental Forest.** Pa. Dep. Forests and Waters, Rep. 4: 1-16, illus.

Pitch pine has outgrown red pine in conversion studies started in 1948, but is rated in second-order preference because it is considered less desirable for timber production. Some pitch pines have been severely browsed by deer, and a few were not windfirm. After 8 years pitch pines had a mean height of 6.3 feet. Factors affecting success of direct seeding on Pocono sites are discussed.

407. McQuilkin, William E., and Eugene F. McNamara. 1967. **Tree planting in scrub oak areas after site preparation with heavy equipment.** USDA Forest Serv. Res. Paper NE-60. 26 pp., illus. NE. Forest Exp. Sta., Upper Darby, Pa.

Describes techniques possible on stony sites where sufficient soil is exposed to permit planting. None of the pitch pines planted on the Dilldown Unit (Delaware-Lehigh Forest) on the Pocono (Pa.) Plateau is developing in good form, so until genetic strains of good form are available, extensive planting of this species is not recommended.

408. Meek, Chas. R. 1929. **Forest tree seedlings for reforestation or for distribution?** J. Forestry 27: 943-948.

Based on a survey of 961 plantations on private land in Pennsylvania, recommendations are made to improve the selection of species and sites, the planting practices, and the care of plantations.

Ten percent of the stock recommended for production is pitch pine. Survival of the 595,996 pitch pines planted in areas included in the survey was 41 percent.

409. Meekins, E. H., H. J. Deion, and C. Tiffany.
1965. **Effect of site preparation on direct seeding conifers in the brush oak type in Rhode Island.** Univ. Mass. Exp. Sta. Bull., Direct Seeding in the Northeast—A Symposium, Proc: 71-73.

In a 1951 burn that was stocked with bear oak, red and white oak, red maple, and pitch pine, these 1964 site-preparation measures were tried: disking in late April and May, controlled burning on 21 May, and a mistblower treatment with Tordon 101 in part of the disked area on 21 May. Treated seeds of pitch pine, larch, and white pine were sown on 22 May. In August stocking was unsatisfactory, possibly because of the drought.

410. Minckler, Leon S.
1948. **Planted pines on claypan soils of southern Illinois.** USDA Forest Serv. Cent. States Forest Exp. Sta., Sta. Note 44. 2 pp., illus.

Eight years after planting 1-1 stock, pitch pines were 14 feet tall with 90-percent survival; those planted as 1-0 stock were 11 feet tall with 70-percent survival. Shortleaf pine is recommended over pitch and Virginia pines because the latter two have excessive branching and crook.

411. Minckler, Leon S.
1955. **Observations on open-grown, non-native conifers in southern Illinois.** Amer. Midland Natur. 54: 460-465, illus.

The one measured pitch pine was 22 inches d.b.h. and 78 years old.

412. Minckler, Leon S., and Arthur G. Chapman.
1954. **Direct seeding of pines in the central hardwoods region.** USDA Forest Serv. Cent. States Forest Exp. Sta. Tech. Paper 140. 20 pp., illus.

Pitch pine was one of six pine species used in a series of experiments. Seeding in spots is not recommended, but suggested procedures are given both for this type of seeding and for seeding in furrows. When seeding in furrows in areas covered by broomsedge or poverty grass, three viable seeds of pitch pine should be sown per linear foot with a push-type mechanical seeder.

413. Minckler, Leon S., and Glenn H. Deitschman.
1953. **Success of planted pines varies with species and site.** USDA Forest Serv. Cent. States. Forest Exp. Sta., Sta. Note 76. 2 pp., illus.

On claypan soils of southern Illinois, planted pitch pines had good survival and fair growth, but after 13 years were 16 to 24 feet tall compared to 32 to 38 feet for loblolly pines and 22 to 26 feet for shortleaf pines. However, the pitch pines were slightly taller than Virginia pines.

414. Newby, A. E.

1968. **Giving nature a hand: NAS Lakehurst reclaims fire-damaged forest.** Navy Civ. Engin. 9(5): 19-20, illus.

Where wildfires had changed stand composition to slow-growing sprouts of pitch pine and scrub oaks, Marden brush-clearing drums were used to chop the existing growth and prepare the site for direct seeding. Plans are to treat 100 acres each spring, and to retreat 8 weeks later. Seeding with cyclone-type hand seeders in January after treatment is at the rate of 70,000 seeds per acre. Pitch pine seedlings reach 7 to 10 inches in height during the first summer.

415. Ostrom, C. E., and Miles J. Ferree.

1942. **Species and sizes of stock for planting in northwestern Pennsylvania.** USDA Forest Serv. Allegheny Forest Exp. Sta. Tech. Note 37. 1 p.

Because of ability to sprout after browsing, planted pitch pines had almost 60-percent survival.

416. Polivka, J. B., and O. A. Alderman.

1937. **The problem of selecting the desirable pine species for forest planting in Ohio.** J. Forestry 35: 832-835.

Pitch pine is considered the least desirable native pine for planting in Ohio, partly because of tip moth damage. White, jack, red, shortleaf, and Austrian pines are recommended ahead of pitch pine. On the basis of examining 295 pitch pines, the authors list the species of insects and leaf diseases and the number of trees damaged by them or by sapsuckers.

417. Rothrock, J. T.

1889. ***Pinus rigida* on the dunes at Cape Henlopen.** Pa. Forest Leaves 2: 83-85, illus.

Pitch pine provided naval stores in colonial days and its wood was used in shipbuilding, for fuel, and for charcoal. Although pitch pine grows on coastal dunes and stabilizes them, its forests can be buried under drifting sand. Advance of the dune at Cape Henlopen, Delaware, is described, and stabilization of the dune by planting pitch pine and other plants is recommended.

418. Sargent, C. S.

1891. **The northern pitch pine.** Gard. and Forest 4 (183): 397, 402, illus.

Pitch pine grows naturally on poor soils—sandy barrens and sour swamps—and is recommended for the barrens of Cape Cod and southern New Jersey where it is the most productive species. Seedlings can be easily raised by sowing seed in open ground. On good sites pitch pine reached diameters of 2 to 3 feet, and such trees were prized for timbers and flooring. As an ornamental, pitch pine might be planted to cover barren knolls.

419. Silviculture Committee, Allegheny Section, Society of American Foresters.

1961. **Tree planting in the Allegheny Section.** USDA Forest

Serv. NE. Forest Exp. Sta., Sta. Paper 158. 18 pp., illus. Upper Darby, Pa.

Describes practices used to establish forest plantations in physiographic regions of the five-state area. Pitch pine is planted in all states, usually as 2-0 stock. Diseases and insects to which planted pitch pines are susceptible are listed. Pitch pine is among the species recommended for planting on bituminous strippings of Pennsylvania and West Virginia.

420. Stevenson, Donald D., and R. A. Bartoo.

1940. **Coniferous forest plantings in central Pennsylvania.** Pa. State Coll. Agr. Exp. Sta. Bull. 394. 20 pp., illus.

Pitch pine is recommended for planting on poor, dry sites. Where planted with red, Scotch, and white pines in 1927, pitch pine surpassed other species in height growth. Average annual increment of pitch pine in pure plantings was 0.23 inches in diameter (b.h.) and 1.24 feet in height. A spacing of 6 by 6 feet is recommended for pitch pine even though diameter growth is greater at wider spacings.

421. Stone, E. L.

1968. **A check list for planting site appraisal.** Cornell Univ. Conserv. Circ. 6(4): 1-4.

Planting of pitch pine is recommended only for sandy or droughty soils, and pitch pine is only one of three or four pine species suggested for these. Indications of sandy or droughty soils are described.

422. Storey, Herbert C.

1951. **Forest and water research project, Delaware-Lehigh Experimental Forest.** Pa. Dep. Forests and Waters. 44 pp., illus.

Studies in converting scrub oak areas of the Poconos to commercial forests are described. Pitch pine was one of the species used in planting and direct-seeding trials, and methods and results are described. Site preparation to favor the establishment of natural reproduction of pitch pine was also tested.

423. Tillotson, C. R.

1921. **Some instances of sand dune planting.** J. Forestry 19: 139-140.

One method for stabilizing dunes near Provincetown, Mass., is to cover land with brush cut from native pitch pine stands and, after this had rotted, plant pitch pine wildlings.

424. U. S. Soil Conservation Service.

1950. **Forestry handbook for the upper Mississippi Region (Ed. 5).** U. S. Dep. Agr., Agr. Handb. 13. 101 pp., illus.

Pitch pine has a medium growth rate and is recommended for planting on heavy and light acid soils and on ridges or southern and western slopes of stripped coal land. Common diseases include Atropellis canker and sweetfern rust.

425. Walters, Russell S.

1959. **Conversion planting on poor hardwood sites shows promise in Ohio.** USDA Forest Serv. Cent. States Forest Exp. Sta. Tech. Paper 168. 5 pp., illus.

Hardwoods were clearcut on a ridge-top site; and pitch, shortleaf, and white pines were planted. After 5 years 71 percent of the surviving pitch and shortleaf pines were free to grow even where not released. Early release favored survival and growth, but in the study area did not appear necessary.

426. Weston, G. C.

1957. **Exotic forest trees in New Zealand.** New Zeal. Forest Serv. Bull. 13. 104 pp., illus.

Pitch pine had been introduced by 1868, and subsequently small plantings had been made. The trees had grown up to 2 feet in height annually in early years and reached 70 feet in height and 15 inches d.b.h. at 47 years. However, planting of pitch pine is suggested only for further trials at high altitudes.

427. Wood, O. M.

1936. **Early survival of some pine interplantings in southern New Jersey.** J. Forestry 34: 873-878, illus.

In a 7-year-old stand of sprout oaks and pitch pine, the interplanting of seedlings of several pine species, including pitch pine, was tried. Drought, competition, and animal damage affected survival of the planted seedlings during the first 4 years.

Natural Regeneration (including harvest cutting, seedbed treatment, and release)

428. Burns, Paul Yoder.

1952. **Effect of fire on forest soils in the Pine Barren region of New Jersey.** Yale Univ. School Forestry Bull. 57. 50 pp., illus.

Effect of 0 to 11 or 15 prescribed burns was studied in two experimental areas with stands of mixed oaks and pitch and shortleaf pines. One was on Lakewood soil; the other on Evesboro soil. Amount, thickness, and N content of the forest floor were determined, as well as chemical properties of the A horizon and the physical properties of the surface mineral soil. Moderate burning treatments did not appreciably modify chemical and physical properties of the mineral soil. Annual burning for long periods had unfavorable effects on the forest floor, but benefited the mineral soil chemically.

429. Frothingham, E. H.

1943. **Some observations on cutover forests in the southern Appalachians.** J. Forestry 41: 496-504, illus.

Pitch pine is mentioned, but is grouped with other yellow pines in results of surveys. In the forest composition these pines were a minor component, and formed a smaller proportion of the new stand than of the original.

430. Little, S.

1953. **Prescribed burning as a tool of forest management in the Northeastern States.** J. Forestry 51: 496-500.

In some forest types fire may have an ecological role. The author described differences among pitch, pond, loblolly, and shortleaf pines in sprouting, production of closed cones, size of seed, desirable seedbed, and seedling growth; and discussed effects of wild and prescribed fires on stand composition in New Jersey and Maryland pine sections, the advantages and disadvantages of prescribed burning, and effects on growth, site, and game.

431. Little, S.

1963. **Mistblower treatments in regenerating preferred species in the forests of New Jersey, eastern Maryland, and eastern Pennsylvania.** NE. Weed Contr. Conf. Proc. 17: 517-526.

For selective release of pitch pines from competing bear, blackjack, black, white, or chestnut oaks, the author recommended mistblower treatments in June, using 2 pounds acid equivalent of the isooctyl ester of 2,4,5-T in 2 quarts of fuel oil and 4 gallons of water. Formulations were suggested for use in preparing sites for natural regeneration in southern New Jersey or for direct seeding of desired species in converting Pocono pitch pine-scrub oak stands.

432. Little, S., and R. H. Fenton.

1964. **1963 results from injector treatments of New Jersey and Maryland hardwoods.** NE. Weed Contr. Conf. Proc. 18: 584-590.

For killing common hardwood associates by individual-stem treatments, the authors recommended complete, low frills, the use of either 2,4,5-T ester or amine, and the application of about 1.5 ml. of 20-, 40-, or 80-pound aehg. solutions to each injector cut. For high kills the first year use 80-pound aehg. solutions.

433. Little, S., J. P. Allen, and H. A. Somes.

1948. **More about the technique of prescribed burning.** USDA Forest Serv. NE. Forest Exp. Sta. 4 pp. Upper Darby, Pa.

For cheap and satisfactory burns under stands, burn only upland sites with fairly continuous fuel at times when firing with the wind gives proper fire intensity; set lines of fire about 1,000 feet apart. To prevent crown scorch (caused by temperatures of 145° F. for 2½ minutes), burn when air temperatures are less than 50°F.

434. Little, S., and E. B. Moore.

1945. **Controlled burning in South Jersey's oak-pine stands.** J. Forestry 43: 499-506, illus.

Effects of 0 to 3 or 5 prescribed burns on mortality and basal wounding of oaks and pitch and shortleaf pines and on establishment of pine reproduction. Effect on shrub height and cover and on forest floor is also described, and recommendations are given on use of fire in seedbed preparation, on cleanings, and on type of harvest cutting. Cost of burning and effect on soils are also discussed.

435. Little, S., and E. B. Moore.
1950. **Effects of prescribed burns and shelterwood cutting on reproduction of shortleaf and pitch pine.** USDA Forest Serv. NE. Forest Exp. Sta., Sta. Paper 35. 11 pp. Upper Darby, Pa.

In two studies in oak-pine stands, the amount of shortleaf and pitch pine reproduction after harvest cutting increased with number of burns before cutting. Shelterwood cutting before burning also encouraged the establishment of pine seedlings, but is less important than burning. Recommended treatments for obtaining adequate and prompt regeneration are given; and losses because of logging damage or drought are described.

436. Little, S., and E. B. Moore.
1952. **Mechanical preparation of seedbeds for converting oak-pine stands to pine.** J. Forestry 50: 840-844, illus.

Different methods of slash disposal and two methods of scarification after seed-tree cuttings were tried. Results indicate that satisfactory reproduction of pitch and shortleaf pines is obtained only when fair or better seed crops occur within the next year. Because of the type of machinery used in this study, subsequent release from hardwood sprouts was necessary.

437. Little, S., and E. B. Moore.
1953. **Severe burning treatment tested on lowland pine sites.** USDA Forest Serv. NE. Forest Exp. Sta., Sta. Paper 64. 11 pp. Upper Darby, Pa.

In pitch pine stands on poorly drained Leon soils, a hot deep-burning fire in late summer or early fall and before or after a seed-tree cutting may eliminate much of the competing vegetation and favor pine reproduction. In the trials described, the first-year catch of pine seedlings on severe burns varied with site from 6,700 to 22,800 per acre—far more than occurred on light burns or unburned areas.

438. Little, S., H. A. Somes, and J. P. Allen.
1952. **Choosing suitable times for prescribed burning in southern New Jersey.** USDA Forest Serv. NE. Forest Exp. Sta., Sta. Paper 51. 7 pp. Upper Darby, Pa. (Also USDA Forest Serv. Fire Contr. Notes 14 (1): 21-25.)

Describes fire-danger ratings when satisfactory burns have been made in oak-pine (pitch and shortleaf) stands, in upland pine stands, and in pine-swamp (pitch pine) stands.

439. Little, S., and H. A. Somes.
1949. **Slash disposal in oak-pine stands of southern New Jersey.** USDA Forest Serv. NE. Forest Exp. Sta., Sta. Paper 31. 12 pp. Upper Darby, Pa.

Slash may form an appreciable hazard where there are dense shrubby understories and thick duff layers. Slash is often not greatly damaging to established reproduction of pitch and shortleaf pines and may protect it from deer browsing. If the seedbed is poor for additional pine reproduction, slash deteriorates it, but has little effect on favorable seedbeds prepared by periodic prescribed fires before harvest cutting.

440. Little, S., and H. A. Somes.

1952. **Poisoning hardwoods in southern New Jersey.** USDA Forest Serv. NE. Forest Exp. Sta. Res. Note 16. 4 pp. Upper Darby, Pa.

Results from using ammate in cups on standing trees of associated species, and from using ammate or a spray of 2,4-D and 2,4,5-T on stumps. To favor pine reproduction, the use of ammate crystals on the edges of freshly cut stumps is suggested wherever vigorous sprouting of oaks after cutting is expected.

441. Little, S., and H. A. Somes.

1961. **Prescribed burning in the pine regions of southern New Jersey and Eastern Shore Maryland—a summary of present knowledge.** USDA Forest Serv. NE. Forest Exp. Sta., Sta. Paper 151. 21 pp., illus. Upper Darby, Pa.

Describes differences between the two sections: the Eastern Shore where loblolly and pond pines are most common, and southern New Jersey where pitch and shortleaf pines predominate. Periodic light winter fires before harvest cutting favor the establishment of pitch and shortleaf pine reproduction (both advance and subsequent) in oak-pine stands and to a lesser extent in pitch pine-scrub oak stands. Such fires are usually not recommended for pitch pine-lowland stands where a hot, deep-burning fire in late summer or early fall seems more desirable for favoring establishment of pine reproduction.

442. Moore, E. B., *et al.*

1946. **Minimum forest practices recommended for the Allegheny Section territory.** J. Forestry 44: 597-599.

Recommended even-aged management, seedbed preparation, and thinning of immature stands in the yellow pine-hardwood type (including pitch and other pines).

443. Somes, H. A., and G. R. Moorhead.

1950. **Prescribed burning does not reduce yield from oak-pine stands of southern New Jersey.** USDA Forest Serv. NE. Forest Exp. Sta., Sta. Paper 36. 19 pp. Upper Darby, Pa.

Data on mortality, basal wounding, basal-area and diameter growth in oak-pine stands subjected to 0 to 10 prescribed winter fires. Mortality and open wounds on pitch and shortleaf pines were limited to stems 1 inch or less in diameter (b.h.). While oaks suffered far more wounding and mortality than pines, damage was concentrated on small, overtopped stems so growth and yields were not affected.

444. Sowers, David W., *et al.*
1956. **Some factors affecting management of conifers and hardwoods in the Allegheny Region.** J. Forestry 54: 563-567.
For stands composed of shortleaf and pitch pines and oaks, recommended measures for pine management include seed-tree cuttings, seedbed preparation chiefly through prescribed burning, a cleaning at 5 to 8 years, thinnings at about 20 years, and a rotation age of about 40 years (pulpwood the chief product).

Stand Improvement

445. Little, S., and H. A. Somes.
1964. **Releasing pitch pine sprouts from old stools ineffective.** J. Forestry 62: 23-26, illus.
A summary of literature and knowledge about the cause of Plains vegetation, and results from reducing competition in present stands. Poisoning all sprout clumps except 400 selected pitch pine sprouts per acre doubled their diameter growth, but did not affect height growth in a 6-year period. Present sprout stands should be converted to seedling stands if trees of merchantable quality are to be grown.

446. McLintock, Thomas F.
1940. **Effect of intensity of pruning on sprout formation in young planted pitch pine.** USDA Forest Serv. Cent. States Forest Exp. Sta. Tech. Note 21. 3 pp.
When applied to 6-year-old planted pitch pines, removal of ¼, ½, or ¾ of the crown induced sprouting on pruned portions of stems. Sprouts on heavily pruned trees were 14 times as dense as on lightly pruned trees.

447. McLintock, Thomas F.
1940. **Growth response of planted pitch pine to differential pruning.** USDA Forest Serv. Cent. States Forest Exp. Sta. Tech. Note 15. 2 pp.
In a 1935 plantation in southern Illinois, first-year response to a 1939 pruning showed that light to heavy pruning did not affect height growth, light to moderate pruning did not appreciably affect diameter growth, and heavy pruning caused a heavy loss in diameter increment. However, this was less at 4.5 feet than at 1.5 feet above ground.

Tree Measurements (Including volume tables)

448. Anonymous.
1935. **Bark thickness.** J. Forestry 33: 624-626.
At breast height, thickness of pitch pine bark varied from 0.19 inch on trees 2 inches d.b.h. to 1.74 inches on 12-inch trees; at 1

foot above ground bark thickness varied from 0.41 inch to 1.99 inches. These thicknesses were similar to those of table-mountain pine, greater than those of Virginia pine, and far greater than those of associated hardwoods.

449. Bartoo, R. A., and R. J. Hutnik.
1962. **Board foot volume tables for timber tree species in Pennsylvania.** Pa. State Forest School Res. Paper 30. 35 pp.
Volume tables for pitch pine according to International and Scribner log rules.

450. Burnham, C. F., M. J. Ferree, and F. E. Cunningham.
1946. **Site class volume tables for merchantable timber in the Anthracite Region of Pennsylvania.** USDA Forest Serv. NE. Forest Exp. Sta. Forest Manag. Paper 3. 16 pp.
Volume tables per tree for pitch pine on class 2 and 3 sites. Merchantable volumes are given in board feet, cubic feet, and tons.

451. Cunningham, F. E., S. M. Filip, and M. J. Ferree.
1947. **Relation of tree-stump diameter to diameter breast high.** USDA Forest Serv. NE. Forest Exp. Sta., Sta. Note 1. 3 pp.
Shows diameter at 0.5 or 1.0 foot above ground for pitch pines 5 to 18 inches d.b.h.; gives reverse relationship.

452. Emmer, R. E.
1941. **Volume table for pitch pine *(Pinus rigida)*, Jackson and Hocking Counties, Ohio.** USDA Forest Serv. Cent. States Forest Exp. Sta. Tech. Note 43. 1 p.
Gross volume in board feet for stems 9 to 18 inches d.b.h. containing one, two, or three 12.3-foot logs.

453. Hampf, Frederick E.
1957. **Relationship of stump diameter to d.b.h. for pitch pine in the Northeast.** USDA Forest Serv. NE. Forest Exp. Sta. Forest Res. Note 65. 3 pp., illus. Upper Darby, Pa.
An equation was developed to show the relationship, and also a graph that permits estimation of diameter at breast height from stump diameter (i.b.) and stump height.

454. McClure, Joe P.
1968. **Predicting tree d.b.h. from stump measurements in the Southeast.** USDA Forest Serv. Res. Note SE-99. 4 pp. SE. Forest Exp. Sta., Ashville, N. C.
Equations for such predictions for pitch pine and 52 other tree species.

455. McCormack, James F.
1955. **An allowance for bark increment in computing tree diameter growth for southeastern species.** USDA Forest Serv. SE. Forest Exp. Sta., Sta. Paper 60. 6 pp., illus. Asheville, N. C.
Growth factors that permit conversion from radial growth inside bark to diameter growth outside bark are given for many southeastern species. That for pitch pine is 2.15; or for 1 inch of radial growth, the diameter increment o.b. is 2.15 inches.

Stand Growth and Development (Including yields)

456. Aughanbaugh, J. E.

1934. **Yield of the oak-chesnut-hard pine forest type in Pennsylvania.** J. Forestry 32: 80-89.

About half of Pennsylvania's forest land is in this type. On typical sites in central Pennsylvania, where the site index for oak at 50 years is 56 feet, pitch pine has a site index of 57 feet. Pitch pine stands produce about 50 percent more volume than stands of oak and associated species (up to 90 years of age).

457. Doolittle, Warren T.

1958. **Site index comparisons for several forest species in the southern Appalachians.** Soil Sci. Soc. Amer. Proc. 22: 455-458, illus.

Measurements taken in nine counties in western North Carolina and one county in northern Georgia showed that site indexes of pitch and shortleaf pines were (1) not significantly different; (2) less than those for Virginia pine, white pine, and scarlet, black, northern red, and chestnut oaks; (3) slightly greater than for yellow-poplar on poorest sites; and (4) slightly more than for white oak on good sites.

458. Ike, Albert F., Jr., and C. D. Huppuch.

1968. **Predicting tree height growth from soil and topographic site factors in the Georgia Blue Ridge Mountains.** Ga. Forest Res. Council Forest Res. Paper 54. 11 pp., illus.

Pitch pine was sampled on 23 plots with a range in site index from 46 to 77 feet. Factors included in the prediction equation for its site index are elevation, position on slope, and steepness of slope.

459. Leete, Bernard E.

1945. **How fast does second-growth timber grow?** Ohio Forest News 42: 35-38.

Describes 20-year changes in stand composition, basal area, and board-foot volume in the Shawnee State Forest, Scioto County, Ohio. As a result of fire protection, shortleaf and pitch pines formed a smaller proportion of the stand after 20 years, although they had a large net gain in volume. The 20-year growth of pines, oaks, and associated species was 1,339 board feet per acre.

460. Moore, E. B., and A. F. Waldron.

1940. **A comparison of the growth of oak and pine in southern New Jersey.** N. J. Dep. Conserv. and Develop. Div. Forests and Parks Tech. Note 10. 6 pp.

Growth of predominantly oak and predominantly pine stands on Sassafras and Lakewood sands are compared. Pine stands were predominantly shortleaf, with some pitch pines; and they grew twice or more as much volume as the oak stands. Data include basal-area, cubic-foot, and board-foot values for a 10-year period in unthinned stands and ones thinned at 30 years.

461. Pinchot, Gifford.

1900. **Effect of fire on forest production.** N. J. State Geol. Annu. Rep. 1899: 109-123, illus.

The original forest was mostly pitch and shortleaf pines; trees were 150 to 200 years old, mostly 15 to 20 inches d.b.h., and 65 to 70 feet tall (maximum of 30 inches and 90 feet). Stands had little undergrowth, and volumes ranged up to 10,000 board feet per acre. Second growth undamaged by fire produced up to 7,500 board feet per acre at 80 years in stands of shortleaf and pitch pine, but fire-damaged stands, many of pitch pine sprouts, yielded far less—0.5 to 7.5 cords per acre in 30 to 40 years.

462. Sargent, Charles S.

1888. **A New Jersey pine forest.** Gard. and Forest 1: 164, 166, illus.

Stems in a pure old-field stand of pitch pine near Lakewood averaged 50 feet in height and 10 inches in diameter at 50 years of age. Such stands are recommended for timber crops on similar soils in New Jersey and on Cape Cod, and direct seeding is suggested for establishing them where natural reproduction is absent.

FOREST DAMAGE & PROTECTION

Weather (including salt spray)

463. Boggess, W. R., and F. W. McMillan.

1954. **Cold weather and glaze damage to forest plantations in southern Illinois.** Univ. Ill. Agr. Exp. Sta. Bull. 574. 23 pp., illus.

Damage to pitch pine by heavy ice accumulation was considerable —about equal to that of shortleaf pine.

464. Boyce, Stephen G.

1954. **The salt spray community.** Ecol. Monogr. 24: 29-67, illus.

Studying the effects of salt spray on dune vegetation of North Carolina and Cape Cod, Massachusetts, shows that much of the damage is not due to wind, but to the deposition of chloride, especially on the seaward side. Pitch pine is considered intolerant to salt spray.

465. Curtis, James D.

1936. **Snow damage in plantations.** J. Forestry 34: 613-619, illus.

Pitch pine in plantations has been damaged by snow, but damage was limited to stems with one-sided crowns.

466. Fenton, Richard H.

1955. **Windthrow a hazard in Virginia pine strip cuttings.** USDA Forest Serv. NE. Forest Exp. Sta. Forest Res. Note 53. 3 pp. Upper Darby, Pa.

Hurricane Hazel in 1954 damaged about 3 percent of the pitch pines in uncut 65-year-old stands of Virginia and pitch pines and hardwoods, but these were in strips 1 chain wide left after cutting strips 2 or 3 chains wide. More trees were broken off than were blown over, and losses among trees 9 inches d.b.h. and larger were more than among those 5 to 9 inches. Damage to Virginia pine was proportionally more than three times that to pitch pine.

467. Hemenway, Ansel F.

1926. **Late frost injury to some trees in central Kentucky.** Amer. J. Bot. 13(6): 364-367, illus.

After a late frost, woody tissues of several tree species were examined for damage. In pitch pine, injury occurred after one to three rows of cells had been formed; and injury resulted in bending or widening of rays, in a dark layer between rays, and in abnormal thickening of some tracheid cell walls. Injury to pitch pine was more severe than that to some other species.

468. Littlefield, E. W.

1942. ***Pinus thunbergii:* a successful exotic on the North Atlantic coast.** J. Forestry 40: 566-573, illus.

Pitch pines on Long Island have been severely attacked by tip moths, leaf miners, and pine scales; and where pitch pines were fully exposed to spray or submergence, trees were killed in the 1938 hurricane.

469. Moss, A. E.

1940. **Effect on trees of wind-driven salt water.** J. Forestry 38: 421-425, illus.

Salt-spray damage in Connecticut from the 1938 hurricane extended 45 miles inland on white pine, the most sensitive species. Pitch pine was among the more resistant tree species.

470. Pinkney, C. Coatsworth.

1944. **Tree valuation, a measure for property loss by hurricane.** Landscape Architect., Oct. 1944: 22-24.

Factors affecting tree values and the evaluation of tree losses in hurricanes are discussed. Felt's table of basic tree values by diameter classes is reproduced, and many species are classed into groups that range from no deduction to 60-percent deduction. Pitch pine was placed in the group of 40-percent deduction.

471. Wallace, Raymond H., and A. E. Moss.

1939. **Salt spray damage from recent New England hurricane.** Nat. Shade Tree Conf. Proc. 15: 112-119.

Describes damage from salt spray carried into Connecticut by the 1938 hurricane. Pitch pine is ranked with Austrian and red pine as resistant.

Fire

472. Banks, W. G., and S. Little.

1964. **The forest fires of April 1963 in New Jersey can point the way to better protection and management.** Soc. Amer. Foresters Proc. 1963: 140-144.

Severe burning conditions of 20 April 1963—conditions that apparently occur only about twice in 50 years—are described, as are the behavior of wildfires on that day, the suppression difficulties, and resulting damage. Measures to prevent similar disasters are suggested, including favoring of pines (pitch and shortleaf) over oaks, and frequent use of prescribed burns.

473. Byram, G. M., and R. M. Nelson.
1952. **Lethal temperatures and fire injury.** USDA Forest Serv. SE. Forest Exp. Sta. Res. Note 1. 2 pp., illus. Asheville, N.C.

Temperatures of 52 to 60°C. are lethal to needles, but the lethal temperature varies with duration of exposure. Susceptibility of pitch pine foliage is somewhat, but not markedly, less than that of loblolly, longleaf, and slash pines.

474. Cumming, James A.
1964. **Effectiveness of prescribed burning in reducing wildfire damage during periods of abnormally high fire danger.** J. Forestry 62: 535-537, illus.

Under extreme burning conditions of 20-21 April 1963, wildfires killed or severely damaged 79 percent of the pines (pitch and shortleaf) 1.6 inches d.b.h. and larger in areas not previously prescribe-burned, but only 17 percent in areas prescribe-burned within the previous 10 years. The wildfire died out in areas with little fuel from prescribed burning in 1962-63. Height of char on tree trunks and proportion of area burned varied with prescribe-burning history. Oaks were more susceptible than pines to fire killing.

475. Gaskill, Alfred.
1910. **How New Jersey is trying to improve her forests.** Amer. Forestry 16: 274-279, illus.

Briefly describes steps taken to improve fire protection of forests: use of local fire wardens in prevention and suppression; requirement of permits for outdoor fires in or near woodlands; and construction and maintenance of firebreaks at least 110 feet wide on each side of railroad tracks through wooded areas. Illustrations show some aspects of pitch pine forests and of fire effects in southern New Jersey.

476. Gustafson, R. O.
1944. **Cull as determined from basal wounds in Kentucky Highlands timber.** J. Forestry 42: 181-184.

In pitch and shortleaf pines there was no cull in the first 8-foot logs of unwounded trees, 5.7 percent cull volume in trees with open wounds (chiefly caused by fires). Proportion of cull in wounded trees of associated hardwood species was much higher, 13 to 34 percent of first-log volume.

477. Little, S.
1945. **Influence of fuel types on fire danger.** J. Forestry 43: 744-749.

In the New Jersey Pine Region fire danger varies with fuel type.

Effects of fuel type and site on wind velocities, drying of natural fuels, and fuel amounts are discussed. Types include oak-pine, (pitch) pine-scrub oak, and (pitch) pine swamps.

478. Little, S., J. P. Allen, and E. B. Moore.
1948. **Controlled burning as a dual-purpose tool of forest management in New Jersey's pine region.** J. Forestry 46: 810-819, illus.

In the pine region of New Jersey, where stands of pitch and shortleaf pines are desired, prescribed burning favors pines over oaks through seedbed preparation and selective killing of hardwoods. But in this section, where devastating wildfires have been common, prescribed burning is especially important in reducing fuels and aiding suppression. The applicable region and sites, methods of burning, costs, and arrangement of areas in practical management are described—as is one case history of controlling a wildfire through prior fuel reduction.

479. Moore, E. B., A. F. Waldron, W. J. Seidel, and S. Little.
1941. **Appraising forest fire damage in New Jersey.** USDA Forest Serv. Allegheny Forest Exp. Sta. Occas. Paper 4. 8 pp.

A technique for appraising wildfire damage is described, based on (1) segregating burned areas into type and age classes, (2) counts of tree numbers and estimates of average diameter (b.h.), and (3) tables on value per tree by species and d.b.h. class. Per-tree values for pitch and shortleaf pines varied from $0.001 for a 2-inch stem to $1.20 for an 18-inch tree.

480. Moore, E. B., A. F. Waldron, W. J. Seidel, and S. Little.
1942. **Forest fuel types of New Jersey.** N. J. Dep. Conserv. and Develop. and USDA Forest Serv. Allegheny Forest Exp. Sta. 59 pp., illus.

Classifies the forest fuel types of New Jersey and assigns relative ratings for spread of fires and resistance to control. Pitch pine is mentioned as occurring in various types, especially the pine-scrub oak and pine lowland. Fires in the latter type are the most difficult to control.

481. Moore, E. B., G. E. Smith, and S. Little.
1955. **Wildfire damage reduced on prescribe-burned areas in New Jersey.** J. Forestry 53: 339-341, illus.

A survey was made to determine relative damage done by a May wildfire in previously prescribe-burned areas as compared to untreated areas. In latter, 64 percent of the trees in oak-pine stands (including pitch pine) were killed or severely damaged, as compared to 17 percent in areas treated once in the previous 3 years. In another area where pitch pine predominated, mostly on lowland sites, prescribed burning during the previous winter prevented spread of a killing wildfire across a property line—except in the path of searing heat from the headfire, where the fire crowned through the pines for about 400 feet into a prescribe-burned area. Prescribed burning both reduces damage and makes fire-control efforts more effective.

482. Nelson, Ralph M.

1952. **Observations on heat tolerance of southern pine needles.** USDA Forest Serv. SE. Forest Exp. Sta., Sta. Paper 14. 6 pp., illus. Asheville, N.C.

Pitch pine was one of the species tested by immersing fascicles in a water bath. Slight differences were found between species. Average lethal temperatures and times varied from 3 seconds at 64°C. to 11.3 minutes at 52°C.

483. Pinchot, Gifford.

1900. **The effects of fire.** N.J. State Geol. Annu. Rep. 1899: 100-108, illus.

Forest fires damage standing timber, destroy young growth and the forest floor, depreciate property values, encourage theft and discourage thrift, and cause general impoverishment in regions where they are common. Each of these effects is discussed. Varying effects of fires on pitch pine are described, and its sprouting in the crown is illustrated.

484. Starker, T. J.

1932. **Fire resistance of trees in northeast United States.** Forest Worker 8: 8-9.

From a questionnaire sent to leading foresters, fire resistance of 22 species was rated. Pitch pine was considered the most resistant.

485. Starker, T. J.

1934. **Fire resistance in the forest.** J. Forestry 32: 462-467.

Fire resistance of species in different parts of the United States is discussed. From a questionnaire answered by 41 foresters, pitch pine was rated as the most resistant species in the Northeast.

486. Stickel, P. W.

1952. **The nature of fire damage to northeastern forests.** *In* Important Tree Pests of the Northeast: 157-161, illus.

Damage from direct killing, basal wounding and delayed mortality, and insect or disease infection is described. Pitch pine is considered the most fire-resistant species, because its bark is relatively thick, is not deeply fissured, and is composed of much corklike tissue.

487. Wood, O. M.

1936. **First year losses after a fire may not represent total mortality.** USDA Forest Serv. Allegheny Forest Exp. Sta. Tech. Note 13. 2 pp.

Mortality of oaks and pines in New Jersey areas burned by 1930 wildfires increased between 1930 and 1932, especially among the pines. In 1930 more pitch pines than shortleaf pines were dead, whereas in 1932 pitch pine mortality was 43 percent compared to 64 percent for shortleaf pine and 54 to 100 percent for associated oak species.

Animals

488. Biswell, H. H., and M. D. Hoover.

1945. **Appalachian hardwood trees browsed by cattle.** J. Forestry 43: 675-676.

Pitch pine foliage was not browsed by cattle on the Coweeta Experimental Forest in North Carolina; but nearly all the foliage of some associated species, such as black locust, was consumed.

489. Bramble, W. C., and M. K. Goddard.

1953. **Seasonal browsing of woody plants by white-tailed deer in the Ridge and Valley section of central Pennsylvania.** J. Forestry 51: 815-819, illus.

A 5-year study was made of seasonal browse perferences in major forest communities of central Pennsylvania. Pitch pine was one of the species heavily browsed—mostly in winter. Little browsing of this species was done in the spring, and none in summer or fall.

490. Church, Thomas W., Jr.

1954. **Mice cause severe damage to Virginia pine reproduction.** USDA Forest Serv. NE. Forest Exp. Sta. Forest Res. Note 35. 2 pp., illus. Upper Darby, Pa.

In two stands on the Beltsville Experimental Forest in Maryland, meadow mice damaged about 60 percent of the Virginia pine reproduction, but only about 11 percent of the young pitch pines. Damaged pitch pines were 0.5 to 0.8 inch in diameter at 1 foot above ground.

491. Hazen, J. F., and O. M. Wood.

1935. **Animal damage in relation to size of planting stock.** USDA Forest Serv. Allegheny Forest Exp. Sta. Tech. Note 4. 2 pp.

Damage by animals, presumably rabbits, was much greater to interplanted pines (pitch and four other species) that were 0.1 to 0.3 foot tall than to stems 0.4 to 0.7 foot tall.

492. Johnson, E. A.

1952. **Effect of farm woodland grazing on watershed values in the southern Appalachian mountains.** J. Forestry 50: 109-113, illus.

Cattle grazed most heavily in cove-hardwood type, secondly on oak-hickory slopes, and hardly at all on pitch pine ridges where associated laurel, azalea, and buckberry occurred. Reduction in tree growth, changes in soil porosity, permeability, and infiltration, and in runoff and turbidity are discussed.

493. Little, Silas, Jr.

1937. **Deer damage to pine reproduction in southern New Jersey.** USDA Forest Serv. Allegheny Forest Exp. Sta. Tech. Note 19. 2 pp.

Damage decreases with increase in height; few seedlings over 3.5 feet tall were injured. Pitch and shortleaf pines were browsed much more than associated Virginia pines.

494. Little, S., G. R. Moorhead, and H. A. Somes.
1958. **Forestry and deer in the pine region of New Jersey.** USDA Forest Serv. NE. Forest Exp. Sta., Sta. Paper 109. 33 pp., illus. Upper Darby, Pa.

Present knowledge of food preferences and availability by seasons and sites, of deer effects on forest practices, and of forest-practice effects on deer are summarized. During the dormant season deer browse on small seedlings and sprouts of pitch and shortleaf pines. Although pines furnish more browse than associated oaks, most of the deer food comes from lowland sites, especially from Atlantic white-cedar.

495. Little, S., and H. A. Somes.
1951. **Deer browsing in New Jersey handicaps pine seedlings.** USDA Forest Serv. NE. Forest Exp. Sta. Res. Note 2: 3-4. Upper Darby, Pa.

Average height growth of pine reproduction in exclosures was twice as much as that of unprotected reproduction. Browsed seedlings gained in height only about a fifth as much as undamaged stems.

496. McQuilkin, W. E., and S. Little.
1952. **Deer repellent fails to protect pine seedlings.** USDA Forest Serv. NE. Forest Exp. Sta. Res. Note 15. 4 pp. Upper Darby, Pa.

Spraying natural reproduction of pitch and shortleaf pines with a repellent (zinc-dithiocarbamate-amine complex plus polyethylene polysulfide) cost $80 an acre for material and labor, but caused only a slight reduction in overwinter browsing by deer (72 percent of untreated stems 0.1 to 1.0 foot tall, 61 percent of those sprayed once).

497. Martin, Alexander C., Herbert S. Zim, and Arnold L. Nelson.
1951. **American wildlife and plants.** 550 pp., illus. McGraw-Hill Book Co., Inc., New York.

Pitch pine is mentioned as especially important to wildlife in the Northeast. Though many birds and rodents are listed as consumers of pine seeds, and several mammals as consumers of foliage, no differentiation is made among species of pine in such food consumption.

498. Mollenhauer, William, Jr.
1939. **Table mountain pine—squirrel food or timber tree?** J. Forestry 37: 420-421, illus.

Branches of table-mountain pine up to 1 inch in diameter are severed by red squirrels to drop the sessile and whorled cones. Similar clipping of branches was not observed on associated pitch, white, and Virginia pines.

499. Perry, Geo. S.
1922. **The special planting problems in Pennsylvania.** J. Forestry 20: 507-512.

Pitch pine is valuable wildlife food because it bears seed at an early age and almost annually; and less than 10 percent of the cones open before January. Some cones remain closed until April or May, but most seeds are released in midwinter. Squirrels feed on unopened cones. Quail, grouse, and many smaller birds eat seeds falling on snow.

500. Smith, Clarence F., and Shaler E. Aldous.
1947. **The influence of mammals and birds in retarding artificial and natural reseeding of coniferous forests in the United States.** J. Forestry 45: 361-369.

Trees squirrels, chipmunks, white-footed mice, and a few species of birds are responsible for most seed losses. Pitch pine is not specifically mentioned.

501. Van Dersal, William R.
1938. **Native woody plants of the United States, their erosion-control and wildlife values.** U. S. Dep. Agr. Misc. Pub. 303. 362 pp., illus.

According to stomach analyses or observations, pitch pine seed or foliage has been consumed by white-tailed deer and by seven species of birds (including ruffed grouse), and is a preferred food of red squirrels.

Diseases

502. Anderson, Gerald W.
1963. **Sweetfern rust on hard pines.** U. S. Dep. Agr. Forest Pest Leafl. 79. 7 pp., illus.

Hosts, life history, symptoms, damage, and control of this fungus are described. Pitch pine is susceptible.

503. Arthur, Joseph Charles, and Frank Dunn Kern.
1914. **North American species of *Peridermium* on pine.** Mycologia 6: 109-138.

The authors describe 16 species of *Peridermium,* and give known hosts and range. Pitch pine is attacked by *P. delicatulum, P. acicolum, P. Rostrupi, P. Comptoniae,* and *P. cerebrum.*

504. Berry, Charles R., and George H. Hepting.
1959. **Pitch canker of southern pines.** U. S. Dep. Agr. Forest Pest Leafl. 35. 3 pp., illus.

Symptoms, damage, control, and hosts of this *Fusarium* fungus are described. It occurs to some extent on pitch pine.

505. Boyce, J. S.
1943. **Host relationships and distribution of conifer rusts in the United States and Canada.** Conn. Acad. Arts and Sci. Trans. 35: 329-482.

Leaves of *Pinus rigida* are the aecial hosts for the rusts *Coleosporium campanulae* (*Peridermium rostrupi*), *C. delicatulum* (*P. delicatulum*). *C. elephantopodis* (*P. elephantopodis*), *C. ipomoeae* (*P. ipomoeae*), *C. lacinariae* (*P. fragile*), *C. solidaginis* (*P. acicolum*), and *C. vernoniae* (*P. carneum*). Pronounced gall-like hypertrophy of pitch pine stems is produced by *Cronartium fusi-*

forme (*P. fusiforme*) and *C. quercuum* (*P. cerebrum*). *Cronartium comandrae* (*P. pyriforme*) and *C comptoniae* (*P. comptoniae*) also infest some stems, but cause little or no hypertrophy.

506. Boyce, J. S.
1952. **Needle cast disease of conifers (caused by *Bifusella, Hypoderma, Hypodermella, Lophodermium*).** *In* Important Tree Pests of the Northeast: 87-89, illus.

Symptoms, injury, life history, and control of needle-cast fungi are described. *Lophodermium pinastri,* the most common species, attacks pitch pine, but is not damaging. *Hypoderma lethale* is prevalent on pitch pine.

507. Campbell, W. A., and Otis L. Copeland, Jr.
1954. **Littleleaf disease of shortleaf and loblolly pines.** U. S. Dep. Agr. Circ. 940. 41 pp., illus.

Although littleleaf disease has been reported on pitch pine, no definite statement can be made about pitch pine's susceptibility, and the disease is not important on this species.

508. Carter, J. C.
1938. ***Coleosporium vernoniae* on *Pinus rigida* in Illinois.** Plant Disease Rptr. 22: 433.

Pitch pines in or planted near a state nursery in Union County, Ill., were lightly to heavily infected with the aecial stage of this fungus.

509. Dearness, John.
1926. **New and noteworthy fungi—IV.** Mycologia 18: 236-255.

In a discussion of 52 species of fungi—including descriptions of the fungus, its host and its known distribution—pitch pine foliage is mentioned as being attacked by *Pezizella minuta, Phacidium convexum, Hypoderma Hedgcockii,* and *H. lethale.*

510. Diller, Jesse D.
1943. **A canker of eastern pines associated with *Atropellis tingens.*** J. Forestry 41: 41-51, illus.

Symptoms, distribution, and damage caused by this canker are described. It usually attacks twigs or branches, and has been found on pitch pine in seven states. No control measures are considered necessary.

511. Doak, K. D.
1934. **Cortical parasitism of conifer-seedling roots in pure culture by mycorrhizal and nonmycorrhizal fungi.** Phytopathol. 24: 6-7.

A fungus resembling *Rhizoctonia silvestris* formed a mantle and network characteristic of ectotrophic mycorrhizae on pitch pine roots, and also infected the cortex of "mother" roots. *Armillaria mellea* infected cortices of "short" and "mother" roots.

512. Doak, K. D.

1934. **Fungi that produce ectotrophic mycorrhizae of conifers.** Phytopathol. 24: 7.

Boletus bicolor, Boletinus brevipes, B. pictis, and Russula lepida formed ectotrophic mycorrhizae with pitch pine roots in culture media.

513. Doak, K. D.

1955. **Pine root reaction in sterile culture to mycorrhizal and other fungi.** Amer. Midland Natur. 54: 443-451, illus.

Armillaria mellea on pitch pine produced rhizomorphs and an intracellular penetration resembling previously reported parasitic behavior. *Boletinus pictus* on pitch pine formed ectotrophic mycorrhizal mantles.

514. Dodge, B. O., and J. F. Adams.

1918. **Some observations on the development of *Peridermium cerebrum.*** Torrey Bot. Club. Mem. 17: 253-261, illus.

On pitch pine in New Jersey this fungus forms globular or fusiform swellings, mostly on trunks. Infections often consist of a number of closely associated swellings formed through a series of migrations by the fungus. Morphology of galls is discussed.

515. Fergus, Charles L., and Frank D. Kern.

1959. **A list of fungi found on trees in Pennsylvania.** Pa. State Univ. Agr. Exp. Sta. Bull. 646. 38 pp.

Lists species found on pitch pine and gives part of tree infected.

516. Hansbrough, J. R.

1952. **Sweetfern blister rust of pitch pines (caused by *Cronartium comptoniae*).** *In* Important Tree Pests of the Northeast: 103-106, illus.

Distribution, life history, damage, and control of this fungus are described. Pitch pine is susceptible to damaging infection.

517. Hatch, A. B., and K. D. Doak.

1933. **Mycorrhizal and other features of the root systems of *Pinus.*** J. Arnold Arboretum 14: 85-99, illus.

Different types of roots and their distinguishing characteristics are described. Included is a photograph of mantle structure and intercellular net of cortical cells in a mycorrhiza from pitch pine.

518. Hedgcock, George G.

1928. **A key to the known aecial forms of *Coleosporium* occurring in the United States and a list of the host species.** Mycologia 20: 97-100.

Pitch pine is host to *C. carneum, C. Elephantopodis, C. Ipomoeae, C. Campanulae. C. Laciniariae. C. Solidaginis. C. Terebinthinaceae,* and *C. delicatulum.*

519. Hedgcock, George G., and Paul V. Siggers.

1949. **A comparison of the pine-oak rusts.** U. S. Dep. Agr. Tech. Bull. 978. 30 pp.

This bulletin deals with host relationships and a morphological comparison of five *Cronartium* species. Pitch pine appears to be about equally susceptible to infection by *C. cerebrum* and *C. fusiforme,* but is less susceptible than some of the pines studied.

520. Hepting, George H., and Marvin E. Fowler.
1962. **Tree diseases of eastern forests and farm woodlands.** U. S. Dep. Agr. Agr. Inform. Bull. 254. 48 pp., illus.

Sweetfern rust stunts, distorts, and may kill pitch pine. Control measures are described. *Atropellis* twig canker also attacks pitch pine.

521. Hepting, George H., and Elmer R. Roth.
1946. **Pitch canker, a new disease of some southern pines.** J. Forestry 44: 742-744, illus.

A *Fusarium* canker found mostly on Virginia pine and rarely on shortleaf and pitch pines is described. Based on studies in North and South Carolina.

522. Hepting, George H., Elmer R. Roth, and Bailey Sleeth.
1949. **Discolorations and decay from increment borings.** J. Forestry 47: 366-370, illus.

None of five pitch pines that were bored developed decay. Holes healed rapidly except where excessive pitch plugs occurred. The wood developed pitch-soaked band seven inches long.

523. Jackson, L. W. R.
1945. **Root defects and fungi associated with the littleleaf disease of southern pines.** Phytopathol. 35: 91-105, illus.

Root defects and fungi associated with littleleaf disease are described, as are results of inoculations on shortleaf pines. Disease is less common on pitch pine than on shortleaf.

524. Kelley, Arthur Pierson.
1930. **Mycorrhizal studies: I. Mycorrhiza of Mont Alto nursery stock.** J. Forestry 28: 34-41, illus.

The mycorrhiza on pitch pine roots is described, and is classed as ectendrotrophic.

525. McKenzie, Malcolm A.
1942. **Experimental autoecism and other biological studies on a gall-forming *Peridermium* on northern hard pines.** Phytopathol. 32: 785-798, illus.

Inoculations of Scotch, jack, and pitch pines were made with aeciospores of a gall-forming rust—presumably *Cronartium quercuum*—from jack and pitch pines. A few of the inoculated pitch pines developed no symptoms of infection, while in others mycelia, but no galls, were produced. In numerous cases bark became roughened, swollen, or discolored. On some pines (pitch ?) leaves were cast, and the leader or whole tree died. Usually cork layers were formed that cut off infected tissue.

526. Mielke, James L.
1961. **Comandra blister rust.** U. S. Dep. Agr. Forest Pest Leafl. 62. 7 pp., illus.

Symptoms, life history, damage, and range of this fungus are described. This rust may girdle and kill trees, but pitch pine is not highly susceptible.

527. Morris, C. L.

1953. **Chemical control of *Hypoderma lethale* on pitch pine.** Plant Disease Rptr. 37: 368-370.

Foliage damage by *Hypoderma lethale* was more serious in Pennsylvania than damage done by a needle-mining insect (*Exoteleia pinifoliella*) or by a rust fungus (*Coleosporium solidaginis*). Much of the damage by *H. lethale* was to needles in the lower part of crowns. Two fungicides tested gave almost complete control, so foliage was retained 8 months longer than on untreated trees.

528. Orton, C. R., and J. F. Adams.

1914. **Notes on *Peridermium* from Pennsylvania.** Phytopathol. 4: 23-26.

Cronartium comptoniae and *Peridermium acicolum* were found on pitch pines in central Pennsylvania.

529. Overholts, L. O.

1917. **An undescribed timber decay of pitch pine.** Mycologia 9: 261-270, illus.

Polyporus amorphus and *P. abietinus* were the principal wood-destroying fungi found in pitch pines that had died and fallen. Fungi and the decay caused by them are described.

530. Overholts, L. O.

1926. **Mycological notes for 1925.** Mycologia 18: 179-184, illus.

Crumenula pinicola, which rarely attacks the twigs of pitch pine in central Pennsylvania, produces cankers and kills infected twigs.

531. Overholts, L. O.

1941. **New species of Polyporaceae.** Mycologia 33: 90-102, illus.

Polyporus lineatus, found on a pitch pine log in Centre County, Pa., produced a brown carbonizing type of rot.

532. Powers, Harry R., Jr., and John S. Boyce, Jr.

1963. **Annosus root rot in eastern pines.** U. S. Dep. Agr. Forest Pest Leafl. 76. 7 pp., illus.

Distribution, hosts, symptoms, spread, damage, and control of *Fomes annosus* are described. This fungus kills pitch pine and other pines, especially in plantations.

533. Roth, Elmer R.

1952. **Roots of living *Pinus rigida* decayed by *Fomes annosus*.** Plant Disease Rptr. 36: 330, illus.

Two uprooted pitch pines near Asheville, N. C., had roots decayed by *Fomes annosus.*

534. Siggers, Paul V.

1955. **Control of the fusiform rust of southern pines.** J. Forestry 53: 442-446, illus.

Life history and distribution of *Cronartium fusiforme,* susceptibility of pines and oaks, canker development, practices affecting susceptibility of trees, and control in nurseries and natural stands are described. Loblolly and slash pines are the main hosts, although pitch pine is also attacked.

535. Slagg, Charles M., and Ernest Wright.

1943. ***Diplodia* blight in coniferous seedbeds.** Phytopathol. 33: 390-393.

Diplodia pinea attacked mature pitch pines on the campus of Kansas State College, and caused dieback by killing foliage of younger and then older needle clusters until the whole shoot on some trees was killed.

536. Spaulding, Perley.

1913. **Notes on *Cronartium comptoniae.*** Phytopathol. 3: 62.

Within one area 147 living pitch pines bore fruiting bodies of *Cronartium comptoniae,* and 8 infected trees had recently died. The fungus apparently causes an annual mortality of about 5 percent.

537. Spaulding, Perley.

1913. **Notes on *Cronartium comptoniae,* II.** Phytopathol. 3: 308-310.

Fruiting of *Cronartium comptoniae* on pitch pines has usually been on stems less than 4 inches in diameter. Thirteen percent of the infected trees, mostly less than 10 feet tall, died within 2 years in one observed area.

538. Spaulding, Perley.

1952. **Red ring root of conifers (caused by *Fomes (Trametes) pini*).** *In* Important Tree Pests of the Northeast: 135-138, illus.

Symptoms, life history, damage, and control of this fungus are described. Pitch pine is one of the conifers frequently attacked.

539. Spaulding, Perley.

1956. **Diseases of North American forest trees planted abroad, an annotated list.** U. S. Dep. Agr. Agr. Handb. 100. 144 pp.

Pinus rigida is known to have been planted in 16 countries in Europe, Asia, Africa, and Australia. *Armillaria mellea* (British Isles, Germany), *Cenangium abietis* (Germany, Poland), and *Lophodermium pinastri* (Denmark, Germany, Russia) have been reported to infest trees in foreign plantings.

540. Spaulding, Perley, and J. R. Hansbrough.

1932. ***Cronartium comptoniae,* the sweetfern blister rust of pitch pines.** U. S. Dep. Agr. Circ. 217. 21 pp., illus.

History of the disease, symptoms, species attacked, distribution, economic importance, life history, and control are described. The disease has been found on pitch pine in 10 states.

541. Stambaugh, William J.
1952. **A study of the needle cast diseases of conifers in Pennsylvania.** J. Forestry 50: 944.
All pitch pines examined in plantations and natural stands were infected with *Hypoderma lethale;* and heavy infections that caused defoliation and growth reduction occurred in 10 to 30 percent of the stands.

542. Underwood, Lucien M., and F. S. Earle.
1896. **Notes on the pine-inhabiting species of *Peridermium.*** Torrey Bot. Club Bull. 23: 400-405.
P. acicolum attacks pitch pine at least in Massachusetts and New Jersey. *P. cerebrum* has been found on pitch pines in those two states and New York.

543. Verrall, A. F.
1964. **Diseases of the hard pines.** *In* Diseases of Widely Planted Forest Trees. FAO/IUFRO Symp. on Internationally Dangerous Forest Diseases and Insects: 56-84.
A list of diseases attacking (1) seedlings, (2) foliage and cones, (3) roots, and (4) stems and branches (including heart rots, cankers, rusts, and mistletoes). Indicates where these diseases occur and on what species, including pitch pine.

544. Weir, James R.
1921. ***Thelephora terrestris, T. fimbriata,* and *T. caryophyllea* on forest tree seedlings.** Phytopathol. 11: 141-144.
Thelephora fimbriata was common on pitch pine seedlings in a Lycoming County (Pa.) nursery.

Insects

545. Aughanbaugh, John E.
1949. **Research—the *Matsucoccus* scale in pitch pine plantations.** Pa. Forests and Waters 1: 182, 186, illus.
Matsucoccus gallicolus Morr. has infested plantations in south-central Pennsylvania since 1931. Symptoms, damage, and data from a plantation in Huntingdon County are given.

546. Beal, James A., and Calvin L. Massey.
1945. **Bark beetles and ambrosia beetles *(Coleoptera: Scolytoidea)*: with special reference to species occurring in North Carolina.** Duke Univ. School Forestry Bull. 10. 178 pp., illus.
Bark and ambrosia beetles, their life histories, damage, and control are described. Ten species that attack pitch pine are listed.

547. Beal, James A., William Haliburton, and F. B. Knight.
1952. **Forest insects of the Southeast: with special reference to species occurring in the Piedmont Plateau of North Carolina.** Duke Univ. School Forestry Bull. 14. 168 pp., illus.
Insects, their damage, life histories, and control are described. Ten species are listed as attacking pitch pine.

548. Behre, C. Edward, and L. H. Reineke.
1943. **The opportunity for silvicultural control of gypsy moth in southeastern Maine.** J. Forestry 41: 811-815.

Pitch pine cover type includes stands dominantly or fully resistant to gypsy moth, whereas the bear oak type has 90 to 100 percent of its composition in favored food species.

549. Bess, Henry A., Stephen H. Spurr, and E. W. Littlefield.
1947. **Forest site conditions and the gypsy moth.** Harvard Forest Bull. 22. 56 pp., illus.

Describes varying populations and damage done by gypsy moths, and weather and forest conditions favoring high and low populations. The pitch pine cover type varies in susceptibility with site, stand composition, and condition. Scrub oak or tree oaks characteristic of dry sites dominate many susceptible stands.

550. Benjamin, Daniel M., J. Donovan Larson, and Arnold T. Drooz.
1955. **The European pine sawfly on the Henderson State Forest, Illinois, with notes on its biology and control** J. Forestry 53: 359-362, illus.

When eggs were laid on pitch pine, needles dried and fell off so that eggs failed to hatch.

551. Brown, R. C., and R. A. Sheals.
1944. **The present outlook on the gypsy moth problem.** J. Forestry 42: 393-407, illus.

Foliage of pitch pine and other pines is unfavorable food for larvae in early stages, but is highly favored by larger caterpillars. In the pine-oak region of Cape Cod, where pitch pine is common, outbreaks of gypsy moth have been frequent, because the hardwoods are mostly oaks. Methods and recommendations on control are discussed, as well as spread of the insect, susceptibility of different forest types, and weather effects.

552. Craighead, F. C.
1950. **Insect enemies of eastern forests.** U. S. Dep. Agr. Misc. Pub. 657. 679 pp., illus.

Important insects that attack eastern forests are described, as are general measures of controlling insect damage. A supplement provides an index to insects by host plants and lists more than 30 insects that attack pitch pine.

553. Eaton, C. B.
1955. **The Saratoga spittlebug.** U. S. Dep. Agr. Forest Pest Leafl. 3. 4 pp., illus.

Describes the insect (*Aphrophora saratogensis*), the damage it does, life cycle, and control. Although pitch pine is a host, severe damage is restricted to red and jack pines.

554. Eaton, C. B., and J. S. Yuill.
1960. **Gouty pitch midge.** U. S. Dep. Agr. Forest Pest Leafl. 46. 8 pp., illus.

Distribution, hosts, symptoms, life history, damage, and control of this insect are described. Pitch pine is the principal host in eastern United States.

555. Felt, E. P., and S. W. Bromley.
1942. **The increasing importance of coleopterous borers in shade trees.** J. Econ. Entomol. 35: 169-171.
Pitch pines weakened by the 1938 hurricane have been attacked by *Dendroctonus terebrans, D. valens,* and *Ips pini,* but only the last has caused severe injury or death of the trees.

556. Felt, E. P., and S. W. Bromley.
1944. **The insect menace to shade trees in the Northeast.** J. Econ. Entomol. 37: 212-213.
Turpentine odor from newly painted buildings attracted *Dendroctonus terebrans* and *D. valens,* which infested nearby pitch pines.

557. Hall, Ralph C.
1935. **Cape Cod pitch pine: its resistance to gipsy moth defoliation and its advantages as a forest tree.** J. Forestry 33: 169-172, illus.
Gypsy moth damage to pitch pine foliage is relatively rare—far less than that to associated oaks, white or red pines, Norway spruce, or European larch. Pitch pine is well adapted to Cape conditions: it is resistant to fires and salt spray; it reproduces well; and in growth rate it compares favorably with associated species.

558. Henry, H. K., and E. W. Littlefield.
1952. **Pine spittle bug *(Aphrophora parallela).*** *In* Important Tree Pests of the Northeast: 66-69, illus.
The insect, its damage, and life history are described, along with recommended methods of control. The insect may be abundant on pitch pine, but causes extensive injury only to Scotch pine.

559. Hoffman, C. H., and R. F. Anderson.
1945. **Effect of southern pine beetle on timber losses and natural restocking.** J. Forestry 43: 436-439, illus.
In Bent Creek Experimental Forest, N. C., this beetle attacked and killed more than 75 percent of the pines 6 inches and larger in limited areas, especially in pure pine stands. Three-fourths of the pines in these groups were shortleaf pine, the remainder were mostly pitch pine. Openings created were restocked mostly by hardwoods.

560. Kowal, R. J.
1960. **Southern pine beetle.** U.S. Dep. Agr. Forest Pest Leafl. 49. 7 pp., illus.
Pitch pine is a preferred species of this insect. Distribution, hosts, evidence of attack, life history, identification, and control of the insect are discussed.

561. McCormick, Jack, and John W. Andresen.
1961. **Infestation of pitch and shortleaf pines by the red pine sawfly in southern New Jersey.** Amer. Mus. Novitates 2032. 6 pp., illus.

Sawflies caused light to heavy defoliation of pitch and shortleaf pines in southern New Jersey during 1956 and 1957. The damage had been attributed to *Neodiprion pratti paradoxicus, N. lecontei,* and *N. pini—rigidae;* but specimens collected and reared by the authors were identified as N. *nanulus nanulus.*

562. McCormick, Jack, and John W. Andresen.
1960. **Some effects of animals on the vegetation of the New Jersey Pine Barrens.** Torrey Bot. Club Bull. 87: 375-385.

Influences of insects (especially locusts, Nantucket pine moths, acorn weevils, and ants); of deer through deer beds, antler rubbing, and urination; and of small mammal excavations are discussed. Some data on the highly variable extent of pine moth damage are presented.

563. Miller, William E., and Ralph B. Neiswander.
1959. **The pitch pine tip moth, *Rhyacionia rigidana* (Fernald), and its occurrence in Ohio (Lepidoptera, Olethreutidae).** Ohio Agr. Exp. Sta. Res. Bull. 840. 23 pp., illus.

Taxonomy, distribution, hosts, seasonal history, damage, and control of pitch pine tip moth are described. Pitch pine is attacked, but not so frequently as red and shortleaf pines.

564. Nelson, Ralph M., and J. A. Beal.
1929. **Experiments with bluestain fungi in southern pines.** Phytopathol. 19: 1101-1106.

Tunnels of southern pine beetles seem insufficient to account for rapid death of attacked trees. From experiments with inoculation of bluestain fungi on pitch and shortleaf pines, wounding during inoculation and infection by fungi together may kill pines in a short time. The authors suggest that fungi are also important in killing beetle-attacked pines.

565. Northeastern Forest Experiment Station.
1956. **1955 annual report.** USDA Forest Serv. NE. Forest Exp. Sta. 118 pp., illus. Upper Darby, Pa.

Describes many of the important insects of the Northeast, their ranges, damage done, and control. Pitch pine is attacked by the pine looper, red-headed pine sawfly, pine spittle bug, and Nantucket pine tip moth.

566. Parr, T. J.
1939. ***Matsucoccus* sp., a scale insect injurious to certain pines in the Northeast (Hemiptera-Homoptera).** J. Econ. Entomol. 32: 624-630, illus.

M. gallicolus feeds chiefly on pitch pine, although it also attacks shortleaf, table-mountain, Virginia, and ponderosa pines in the Northeast. Damage, life history, distribution, and possible control of this insect are described. It attacks all ages of pitch pine from 3-year-old seedlings to mature trees, and is most destructive to stems 10 to 30 feet tall, especially those weakened by drought or other adverse conditions.

567. Ripley, Thomas H.

1962. **Tree and shrub response to recreation use.** USDA Forest Serv. SE. Forest Exp. Sta. Res. Note 171. 2 pp. Asheville, N.C.

Of five conifers, pitch pine is rated fourth most resistant to damage correlated with public use of camping and picnicking sites in the Cherokee, Nantahala, and Pisgah National Forests in North Carolina and Tennessee. Many associated hardwoods seemed more resistant to disease and insect attacks in recreational areas.

568. Ross, Herbert H.

1955. **The taxonomy and evolution of the sawfly genus *Neodiprion*.** Forest Sci. 1: 196-209, illus.

A key to the species is given, and critical species are described. Pitch pine is listed as a host for *N. pini-rigidae, N. sertifer,* and *N. pratti paradoxicus.*

569. Schaffner, J. V., Jr.

1943. **Sawflies injurious to conifers in the Northeastern States.** J. Forestry 41: 580-588, illus.

General habits, life cycles, damage done, and control of sawflies. A key for identification of Northeastern species is given, and the individual species are discussed. Damage to pitch pine by *Neodiprion dyari, N. lecontei,* and *N. pini-rigidae* is described.

570. Schaffner, J. V., Jr.

1952. **Pine sawflies (Tenthredinidae and Pamphiliidae).** *In* Important Tree Pests of the Northeast: 9-15, illus.

Includes descriptions of larvae and life histories of several sawflies and of the pine false webworm; and suggests control methods. Pitch pine is a host of *Neodiprion lecontei, N. pinetum, N. pini-rigidae,* and *N. dyari.*

571. Schaffner, J. V., Jr., and H. L. McIntyre.

1944. **The pine root-collar weevil.** J. Forestry 42: 269-275, illus.

Discusses characteristics, life history, habits, economic importance, and control of *Hylobius radicis.* Although pitch pine is attacked, no serious injury has usually resulted.

572. Wilson, Louis F., and Donald C. Schmiege.

1965. **Pine root collar weevil.** U. S. Dep. Agr. Forest Pest Leafl. 39. 7 pp., illus.

Damage is most severe in plantations, especially on poor sites and usually before crown closure. Hosts, life history, damage, and natural and artificial control of this insect (*Hylobius radicis*) are described. Pitch pine is one of the least susceptible hosts.

WOOD TECHNOLOGY & UTILIZATION

573. Betts, H. S.

1954. **The southern pines.** USDA Forest Serv. Amer. Woods Series. 13 pp., illus.

Pitch pine is one of the less important yellow pines, but the woods of several species are so similar that they are described together. Discusses the distribution of the four most important species, their volumes and uses, and wood properties of the whole group.

574. Brown, H. P., and A. J. Panshin.

1940. **Commercial timbers of the United States.** 554 pp., illus. McGraw-Hill Book Co., New York.

Pitch pine is grouped with other yellow or hard pines of eastern United States, and the wood anatomy and uses of this group are described (pp. 376-378).

575. Bull, Marcus.

1826. **Experiments to determine the comparative quantities of heat, evolved in the combustion of the principal varieties of wood and coal, used in the United States, for fuel; and, also, to determine the comparative quantities of heat lost by the ordinary apparatus, made use of for their combustion.** Franklin J. and Amer. Mech. Mag. 1: 257-293, illus.

Specific gravity of dry wood of pitch pine is 0.426; weight per cord, 1,904 pounds. A cord of dry wood yields 510 pounds or 33 bushels of charcoal.

576. Forest Products Laboratory, USDA Forest Service.

1955. **Wood handbook, basic information on wood as a material of construction with data for its use in design and specification.** U. S. Dep. Agr. Agr. Handb. 72. 528 pp., illus.

Heartwood of pitch pine is brownish red and resinous; sapwood is thick and light yellow. The medium heavy to heavy wood is used for lumber and fuel, weighs 34.9 pounds per cubic foot at 15-percent moisture content or 2,910 pounds per thousand board feet (2,130 pounds when dressed). The wood is rated as medium strong, medium stiff, medium hard, medium high in shock resistance, and medium small to medium large in shrinkage. Amounts of radial, tangential, and volumetric shrinkage are given for drying to 20-, 6-, and 0-percent moisture content.

577. Grabow, Rudolph H.

1923. **Suitability of various American woods for pulp and paper making.** J. Forestry 21: 462-474.

Structure and pulping qualities of pitch pine wood are similar to those of shortleaf, loblolly, longleaf, slash, and Virginia pines. Yields in the sulphate process are about 40 percent compared to 50 percent for spruces.

578. Hall, William L., and Hu Maxwell.

1911. **Uses of commercial woods of the United States: II. Pines.** USDA Forest Serv. Bull. 99. 96 pp.

Physical properties of the wood, supply, and early and contemporary uses of pitch pines are described. Uses have included production of tar, shoemaker's wax, fagots for light, water wheels, building timbers, fence rails, boats, bridge timbers, mine props, boxes and crates, flooring and interior finish, barrel headings, piling, pulp, and fuel.

579. Hardy, Eric.

1942. **Woods for dye vats and chemical storage.** Textile Recorder 60 (711): 35, 37.

Vats made of pitch pine are serviceable for many cold acids, but its wood contains too much resin for use with hot liquids.

580. Ifju, Geza.

1969. **Within-growth-ring variation in some physical properties of southern pine wood.** Wood Sci. 2:11-19, illus.

Describes results from testing one tree of each of six species, including pitch pine. Gives for pitch pine values of specific gravity, tensile strength, and modulus of elasticity for 13 to 82 replicates at 3 positions: rings 8-10, 18-20, 28-30—all at breast height.

581. Markwardt, L. J.

1930. **Comparative strength properties of woods grown in the United States.** U. S. Dep. Agr. Tech. Bull. 158. 38 pp., illus.

Gives comparative properties of clear wood by species (including pitch pine): specific gravity, weight per cubic foot, shrinkage (radial and tangential), bending strength, compressive strength, stiffness, hardness, and shock resistance.

582. Markwardt, L. J., and G. E. Heck.

1938. **Standard terms for describing wood.** J. Forestry 36:3-11.

Pitch pine wood is moderately heavy (specific gravity 0.45), has a moderately small shrinkage in drying (110), moderately strong bending strength (80) and compressive strength (76), a moderately weak composite bending and compressive strength (78), a moderately high shock resistance (96), and it is moderately stiff (146), and moderately hard (56). (Data about the same as in Markwardt 1930.)

583. Markwardt, L. J., and T. R. C. Wilson.

1935. **Strength and related properties of woods grown in the United States.** U. S. Dep. Agr. Tech. Bull. 479. 99 pp., illus.

For pitch pine and other species, this bulletin gives strength and related properties of wood samples: specific gravity, weight, shrinkage, static bending, impact bending, compression, hardness, shearing strength, cleavage, and tensile strength. Data for pitch pine are given separately for samples from Tennessee and Massachusetts.

584. Mathewson, J. S.
1930. **The air seasoning of wood.** U. S. Dep. Agr. Tech. Bull. 174. 56 pp., illus.

Shrinkage values, specific gravity, and weight per cubic foot for pitch pine and for other species.

585. Newlin, J. A., and Thomas R. C. Wilson.
1917. **Mechanical properties of woods grown in the United States.** U. S. Dep. Agr. Bull. 556. 47 pp., illus.

Results of tests made on pitch pine samples from Tennessee. (See also Markwardt and Wilson 1935).

586. Pomeroy, Kenneth B.
1952. **Modern trends in an ancient industry.** J. Forestry 50: 297-299, illus.

In 1715 a law was passed in Massachusetts to forbid the boxing of pitch pines on Cape Cod for turpentine.

587. Sargent, Charles S.
1884. **Report on the forests of North America (exclusive of Mexico).** U. S. Dep. Int. Census Office, 10th U. S. Census (1880), vol. 9: 1-612, illus.

Describes distribution, wood characteristics, and properties, and lists taxonomic references for pitch pine and other species.

588. Sim, Robert J., and Harry B. Weiss.
1955. **Charcoal-burning in New Jersey from early times to the present.** 62 pp., illus. N. J. Agr. Soc., Trenton.

Pitch pine was the principal wood used in charcoal production. Tar, resin, and pitch also were obtained. The open-pit method of charcoal burning is described, and some information on yields (about 30 bushels of charcoal per cord of wood) is given. In the days of bog-ore furnaces, stands were cut over at 20-year intervals for charcoal.

589. Wells, Sidney D., and John D. Rue.
1927. **The suitability of American woods for paper pulp.** U. S. Dep. Agr. Dep. Bull. 1485. 101 pp., illus.

The suitability of pitch pine and other species for pulp by sulfite, sulfate, and mechanical processes is discussed. Yields, bleach required, and uses of pulp are given. Pitch pine pulp by the sulfate process is suitable for kraft wrapping paper, fiber board, and book stock.

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Measuring Forest
EVAPOTRANSPIRATION
—Theory and Problems

by C. Anthony Federer

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SOME BASIC PROBLEMS

A SATISFACTORY general method of measuring forest evapotranspiration has yet to be developed. Many procedures have been tried, but only the soil-water budget method and the micrometeorological methods offer any degree of success. This paper is a discussion of these procedures and the problems that arise in applying them. It is designed as a reference for scientists and management specialists working in forest hydrology and meteorology.

In forest hydrology, problems that require knowledge of the amount of water being lost to the atmosphere by evaporation and transpiration can be divided into two major groups: (1) estimating evapotranspiration from an existing fully forested surface, and (2) predicting the changes in evapotranspiration that would follow any given treatment. These problems can generally be subdivided according to the time and area scales involved. Water-yield problems may be of concern on an annual, seasonal, monthly, or even weekly basis. Flood-prediction problems may require knowing the changes in soil-water storage by monthly, weekly, or even shorter intervals. The area of the watershed under study can range from a few acres to thousands of square miles.

At some time, apparently still in the distant future, we can expect that a rational procedure for estimating forest evapotranspiration will be developed — based on soil, vegetation, and topographic parameters and soil and atmospheric variables. But we are still searching for basic understanding of the many processes involved in the translocation of water from the soil to the atmosphere. Concurrently, we are trying to develop techniques that can be used to measure evapotranspiration under some limiting conditions for application to some of the hydrologic problems discussed above.

The standard device for accurate measurement of evapotranspiration from agricultural crops is a weighing lysimeter. Other techniques are generally tested against a lysimeter. Unfortunately, because of the size of forest vegetation, the weighing lysimeter is unsuitable for forest evapotranspiration studies. In the gaged-watershed approach to forest hydrology, the watershed is considered as a large unweighed lysimeter. If precipitation is measured, and if measured streamflow represents all surface and subsurface water loss from the watershed, then the gaged watershed gives evapotranspiration by difference for any period in which soil water storage at the end is the same as at the beginning. This last restriction often limits the method to annual or perhaps to growing-season values. Unmeasured surface and subsurface losses often invalidate this method completely.

The sapflow method, which measures the rate of water movement in the tree stem, cannot yet be used to determine transpiration rates *(Swanson 1967)*. The quick-weighing method of measuring the weight loss of excised leaves or branches has been used by Rutter *(1966)* to obtain forest transpiration, but this method is laborious and gives only instantaneous values. And the method of enclosing a branch or whole tree in a tent and measuring the water vapor gained by the air is unsatisfactory because it alters the transpiration rate. These three methods, which are discussed by Swanson and Lee *(1966)*, are subject to great sampling errors; and they give values of transpiration only.

Empirical techniques have been used to estimate evapotranspiration from measured evaporation loss of a small water surface (an evaporation pan or atmometer) or from one or two meteorological parameters such as air temperature, saturation deficit, or solar radiation. But the applicability of these or any other such methods proposed in the future cannot be tested unless a suitable method of actually measuring forest evapotranspiration can be found.

The application of either the soil-water budget method or the micrometeorological approaches to large watersheds will remain impractical because of the spatial sampling involved. Evapotranspiration from large watersheds must continue to be evaluated by semi-empirical techniques. However, continual improvement of these techniques must be based on studies involving the soil-water budget and micrometeorological methods on smaller areas. The soil-water budget method, in which the change of soil water content is measured, has been the normal method for experimental plot studies for a long time.

Micrometeorological methods of determining evapotranspiration for crop, soil, and water surfaces have been developed only in the past 15 years. These involve measuring the energy balance of the surface and the turbulent transfer of heat and vapor in the air above the surface. The development of these methods has greatly increased understanding of the physical factors controlling the evaporation process.

THE SOIL-WATER BUDGET METHOD

The familiar water-balance equation provides one approach to measuring forest evapotranspiration *(Burroughs and Schultz 1965)*. In its most general form for any given soil-vegetation volume, this equation[1] can be written

$$\hat{E} = P \pm F \pm G \pm \Delta W \qquad (1)$$

where $\hat{E}$ is the water output above the surface or evapotranspiration; P is the water input above the surface or precipitation; F is the flow in or out on the surface, or streamflow; G is the flow in or out below the surface, or deep seepage; and ΔW is the change in water content of the soil and vegetation volume, and of snow cover. The four terms on the right side of the equation must be measured in order to evaluate $\hat{E}$; but under some conditions any one, two, or three terms may be negligible.

We do not need to discuss the measurement of precipitation and surface runoff here. But note that P must be measured above the canopy if interception is to be included in $\hat{E}$. Also, there may be surface inflow in some situations.

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[1] See Appendix for a description of the values in equations (1) to (14).

The deep seepage term, G, has always been a bugaboo. Any loss or gain of water through the bottom or sides of the soil volume sampled for the $\triangle W$ term is included. If the whole soil volume is relatively dry, deep seepage may be negligible; but movement can occur when the soil is drier than field capacity *(Hewlett and Hibbert 1963)*. When a true water table is present, knowledge of the spatial variation of the height of the water-table surface and the hydraulic conductivity of the soil may be sufficient for estimating the inflow or outflow. Similarly, for soils drier than saturation, the appropriate soil-water suction gradients and the hydraulic conductivity will give, at least in theory, the inflow or outflow *(Holmes 1960; Rose and Stern 1965)*. Practical problems with instrumentation as well as sampling and theoretical difficulties, especially with hysteresis, cannot be overemphasized. Several methods of indirectly estimating deep seepage have also been devised *(Slatyer and McIlroy 1961; Willardson and Pope 1963)*.

Much has been written about measuring soil water storage. Slatyer and McIlroy *(1961)*, *Taylor* et al. *(1961)*, and Cope and Trickett *(1965)* have given critical reviews of the various methods. For some studies, electrical resistance units may be satisfactory *(Rutter 1964)*. However, present practice favors the neutron-scattering technique. The problem of stones in inserting access tubes is being overcome by use of power drills *(Koshi 1966; Richardson 1966)*. Attempts to achieve satisfactory measurements within the surface 30 cm. *(van Bavel 1961)* have led to commercial surface probes and shields for depth probes *(Pierpoint 1966)*, but the usefulness of surface-probe measurements in evapotranspiration studies has yet to be determined.

Hewlett, et al. *(1964)* showed that instrument and timing errors in the neutron-scattering method are insignificant compared to the spatial sampling error for Carolina forest soils. They also showed that in time, repeated sampling at the same points causes the standard error of the change in mean water content to be only one-third of the standard error of the mean absolute water content. This advantage is not obtained with gravimetric sampling.

Hewlett, et al. *(1964)* obtained a standard error of about 0.3 percent water content for 30 samples over several acres, each having 30-second timing intervals. They showed that further increase of the number of sampling locations or the sampling time would not significantly reduce the standard error. Converting the 30 samples from percent by volume to inches of water, assuming a 75 cm. soil depth, yields 0.22 cm. as their standard error. This is of the same order of magnitude as the daily evapotranspiration, so accurate daily difference in soil-water content appear to be impossible to detect unless the soil is extremely homogeneous. The soil-water balance thus cannot give meaningful values of evapotranspiration for periods of less than 3 or 4 days.

Many studies have been made of the water balance of forests, often to determine differences in evapotranspiration among cover types over weekly periods *(Zahner 1955; Lull and Axley 1958)*. Sometimes inadequate attention is paid to the deep seepage problem, so results must be carefully evaluated. The soil-water balance approach provides information on rooting depth and soil-water content, but it gives no information about the meteorological factors that govern evapotranspiration.

MICROMETEOROLOGICAL APPROACH

Two basic principles underlie the micrometeorological methods of determining evapotranspiration: the change of phase involved in evaporation requires an energy supply, and the removal of water vapor by the atmosphere is associated with a vapor-concentration gradient. Two assumptions are necessary to develop the present theories: the evaporating surface must be considered two-dimensional and horizontal, with solid (or water) below and air above the interface; and the surface must be infinite in extent. These assumptions are required so that the energy and vapor flow is all vertical; there is no net flow in horizontal directions.

Energy Balance

The energy used in evapotranspiration, L_vE, is the product of the latent heat of vaporization, L_v, and the mass loss of water, E. This energy must be supplied from energy sources. In fact, since the ideal surface is only two-dimensional, conservation of energy requires that as much energy reaches the surface as leaves the surface. The other sources and sinks of energy are the net radiant energy gained or lost, Rn (net radiation); heat gained or lost by air above the surface, H (sensible heat); heat gained or lost by soil and vegetation, S; and heat used in metabolism (mainly photosynthesis minus repiration), M. Melting or freezing of snow also acts as a heat sink or source, which will not be considered here. The resulting surface energy-balance equation, when solved for evapotranspiration, is

$$L_vE = Rn - H - S - M \tag{2}$$

All terms in this equation may have units of energy per unit surface area per unit time or, when integrated over a given time period, just energy per unit area. Net radiation is here positive for energy flow to the surface, while other terms are positive for flow away from the surface. For forests on a normal summer day, all terms are then inherently positive. But in other conditions, any one or more of the terms can become negative: L_vE during dew formation, Rn at night, H at night or during advection (see below), S at night or in the autumn, and M at night due to respiration.

Table 1.—*Diurnal energy balance of a young fir forest*[1]

Flux	Time				Daily Total
	1-2 a.m.	7-8 a.m.	12-1 p.m.	5-6 p.m.	
		Calorie cm^{-2} min^{-1}			*Calorie cm^{-2}*
Rn	—0.06	0.55	1.17	0.38	586
L_vE	— .01	.44	.74	.22	386
H	— .02	.06	.38	.18	197
S	— .02	.00	.03	.01	3
M	— .01	.05	.02	—.03	0

[1] Baumgartner (1956).

Table 1 shows the values of these energy-balance components for a fir forest on a clear summer day *(Baumgartner 1956)*. Other types of forest, and, indeed, other agricultural surfaces, show energy balances similar to this. The S and M terms are generally small for closed forests; and they may be measured or estimated with sufficient accuracy, or else ignored.

The net radiation is actually a combination of two types of radiation — solar and thermal — each of which is transferred both toward and away from the surface (downward and upward). Since most of the energy required for evaporation is supplied by solar radiation, R_s, evaporation is more closely related to R_s than to any other single variable. The fraction of R_s that is reflected by the surface is called the albedo, a. Thermal radiation, also called terrestrial, infrared, or longwave radiation, is emitted both downward by the atmosphere, R_{td}, and—in usually larger amounts—upward from the surface, R_{tu}. The upward component is primarily emission from the surface, which is governed by the surface temperature, T_o, but also includes a reflected part of the downward thermal radiation. Combining these radiation fluxes suitably gives the net radiation

$$Rn = (1 - a)\, R_s + \varepsilon\, R_{td} - \varepsilon\, \sigma\, T_o^4 \qquad (3)$$

where ε is the absorptivity or emissivity of the surface for thermal radiation and σ is the Stefan-Boltzmann constant.

Net radiation can be measured directly with a suitable radiometer; but the other two important terms in the energy balance, L_vE and H, are difficult to measure directly for forests. These two are closely related to the turbulent transfer processes in the atmosphere. Thus it is not possible to find evaporation by the energy balance alone; we must consider the aerodynamic properties of the atmosphere.

Aerodynamic Equations

Four important quantities are transferred vertically by movement of the air above any surface: heat, water vapor, momentum, and carbon dioxide. In each case, the flux in question is proportional to the vertical gradient of, respectively, temperature, water vapor concentration, wind speed, and CO_2 concentration. The CO_2 flux is important in plant growth studies but does not concern us here.

Sensible heat is heat transferred to or away from the surface because the surface is colder or warmer than the air above. Momentum transfer from the air to the surface is due to friction exerted on the air moving over the surface and is evidenced by lower wind speed closer to the surface. Water vapor generally moves away from the wet surface into the drier air as evaporation; but sometimes it moves in the reverse direction, resulting in condensation as dew or frost.

The equations governing these transfer processes are similar:[2]

$$H = -C_p \rho K_h (dT / dz) \qquad (4)$$

$$E = -\rho K_w (dq / dz) \qquad (5)$$

$$\tau = \rho K_m (du / dz) \qquad (6)$$

The sensible heat flux, H, and the water vapor flux, E, appeared above in the energy-balance equation (2). The momentum flux is τ. The density of the air, ρ, and its specific heat, C_p, are considered constants. The transfer coefficients or diffusivities, K_h, K_w, and K_m for heat, water vapor, and momentum, respectively, are not constant but vary with windspeed, surface roughness, height, and sensible heat flux, H. The terms in parentheses represent the vertical gradients or change with height z, of air temperature, T; specific humidity, q; and wind speed, u.

The three transfer coefficients are closely related, since all are dependent on the turbulent properties of the atmosphere. Many experiments have shown that

$$K_m = k u_* z / \phi_m \qquad (7)$$

where k is the von Karman constant, ϕ_m is a stability correction, and u_* is a form of the momentum flux called the friction velocity, which is defined as

---

[2] The gradients here and later in this report can be written as total derivatives (dT/dz) rather than as partial derivatives ($\delta T/\delta z$) because horizontal homogeneity and steady state conditions are assumed. When this assumption does not hold, advection occurs (see page 00). And to be strictly correct, the adiabatic lapse rate, 0.01°C m^{-1}, should be subtracted from dT/dz.

$$u_* = (\tau / \rho)^{1/2} \qquad (8)$$

When the sensible heat flux, H, is zero (neutral or adiabatic condition), the stability parameter, ϕ, is unity. This case is the regime of fully forced convection in which turbulence is produced only by friction due to wind movement over the rough surface. When H is positive (unstable or lapse condition), free convection due to rising warm air and sinking cold air increases the turbulence, which effectively decreases ϕ to some value less than unity. When H is negative (stable or inversion condition), the turbulence is damped and ϕ increases to a value greater than unity.

By an analogy called the similarity hypothesis, the other two diffusivities are similarly defined as

$$K_h = k\,u_*\,z / \phi_h$$

$$K_w = k\,u_*\,z / \phi_w$$

Many scientists assume $\phi = \phi_m = \phi_h = \phi_w$, and thus $K = K_m = K_h = K_w$ as a satisfactory first approximation. This is certainly true in neutral conditions when all ϕ values are unity. But the question of equality of the transfer coefficients in diabatic conditions is an unsolved problem in micrometeorology. Several investigations indicate that K_h may be twice as large as K_m in extremely unstable conditions and only half as large in extremely stable conditions *(Drimmel 1968; Record and Cramer 1966).* Researchers had thought that K_w was approximately equal to K_m *(Deacon and Swinbank 1958),* but recent investigations by Dyer *(1967)* indicate that $K_w = K_h$. Until differences are quantitatively established, equality will have to be assumed for practical work.

A second unsolved micrometeorological problem is the form of ϕ under varying stability conditions. Usually ϕ is given as a function of one of four other stability parameters: the Richardson number in either its flux or gradient forms (R_f and Ri), and the Monin-Obukhov dimensionless height in either its flux or gradient forms (z / L and z / L′). These are defined here for reference:

$$R_f = \frac{-gH}{C_p \rho u_*^2 T (du/dz)} = \frac{K_h}{K_m} \quad Ri = \frac{K_h}{K_m} \frac{g (dT/dz)}{T (du/dz)^2}$$

$$\frac{z}{L} = \frac{-zgkH}{C_p \rho u_*^3 T} = \frac{K_m}{K_h} \frac{z}{L'} = \frac{K_m}{K_h} \frac{zgk (dT/dz)}{u_* T (du/dz)}$$

where g is the acceleration of gravity and T is the air temperature. The terms are further interrelated since

$$R_f \phi_m = z / L$$

All the parameters R_f, Ri, z / L, and z / L′ increase in absolute value nearly linearly with height. The Richardson number at any height z can be found by:

$$Ri = \left[\frac{g (T_2 - T_1)}{T (u_2 - u_1)^2} \ln \frac{z_2}{z_1} \right] z$$

with T the mean of T_1 and T_2.

When the transfer coefficient is to be determined from wind and temperature measurements, the form of ϕ must be known. Although theory requires functions of ϕ involving R_f or L, these cannot be used in practice unless H is independently evaluated through use of such techniques as the eddy correlation method (see below). Therefore, practical forms of ϕ are functions of Ri and L′ and thus involve implicit assumption of $K_m = K_h$. Monin and Obukhov *(1954)* introduced a linear relation between ϕ and z / L′. However, this relation contained an empirical coefficient that has been found to vary with stability *(Pandolfo 1963; O'Brien 1965)*, so a number of more complex forms have been proposed *(Panofsky 1963; Swinbank 1964; Webb 1965)*. Brutsaert *(1965)* has given an excellent summary of these relations and their use in evaporation measurements. Bernstein *(1966)* and others who have used existing data to compare these forms find that the experimental data is not good enough to show that one form is better than another. Thus, in practice, nearly any of the forms may be chosen. In cases of extreme stability and instability, no proposed forms will fit the data adequately.

The friction velocity, u_*, can be found from the integrated form of the combined equations 6, 7, and 8:

$$u_* = \frac{k\,(u_2 - u_1)}{\ln[\,(z_2 - D)\,/\,(z_1 - D)\,] - \psi} \tag{9}$$

$$\text{where } \psi = \int_{z_1 - D}^{z_2 - D} \frac{1 - \phi}{z}\,dz$$

and u_1 and u_2 are wind speeds measured at two heights above the canopy, z_1 and z_2. ψ is the integrated form of the stability correction, which depends on z_1 and z_2. The zero-plane displacement, D, is a correction to the measured heights of the sensors above the ground, z_1 and z_2. D is about equal to the general height of the vegetation and allows for the fact that the top of the canopy, and not the ground level, influences the wind above the trees.

If we extrapolate this wind profile toward the surface, u_1 approaches zero as $z_1 - D$ approaches a constant, z_0. The parameter z_0, is called the roughness length and is characteristic of the physical roughness or turbulence-inducing properties of the surface. If z_0 and D are known for forests, u_* can be obtained by measuring u at only one height. D and z_0 must be found from measuring wind speed at several heights, and very accurate measurements are required *(Robinson 1961; Covey 1962; and Panofsky 1963)*. For forests z_0, is of the order of 1 m., while the zero plane displacement is somewhat less than the height of the trees *(Baumgartner 1956; Rauner 1960)*.

Mass-Transfer or Profile Method

Substituting (9) into (7) and then into (5) and integrating gives the mass-transfer equation for E as

$$E = -\rho k^2 \frac{(u_2 - u_1)\,(q_2 - q_1)}{\left[\ln\left(\frac{z_2 - D}{z_1 - D}\right) - \Psi\right]^2} \tag{10}$$

This equation can be used directly for finding evapotranspiration. It requires wind and vapor concentration measurements at two heights above the surface and temperature measurements for the stability correction. The measurement accuracies required are high, since the differences are small. Baumgartner *(1956)* found that this method worked well over a forest at night, but it was unsatisfactory during the day because of insufficient measurement accuracy. Deacon and Swinbank *(1958)* have proposed a modification that eliminates the temperature measurements for the stability correction and assumes a constant but undetermined roughness length.

Bulk aerodynamic methods use surface values, $u_1 = 0$, $(z_1 - D) = z_o$, and $q_1 = q_o$, in the form

$$E = -\rho k^2 \frac{u_2}{\left[\ln\left(\frac{z_2 - D}{z_o}\right) - \psi\right]^2}(q_2 - q_o) \qquad \textbf{(11)}$$
$$= f(u_2)\,(q_2 - q_o)$$

This method involves only wind speed at one height but requires constancy of surface roughness. The exacting measurement of z_o must be made at the outset, or else the wind function f (u_2) can be obtained empirically. The stability correction, if not ignored, requires measurement of temperature at two heights. The surface humidity, q_o, cannot be measured directly except over water, where it is equal to the saturation specific humidity at temperature T_o. We should note here that

$$q = \frac{0.622}{p}\,e$$

where p is atmospheric pressure and e is vapor pressure in the same units as p.

Eddy Correlation Methods

Vertical transport of heat and water vapor in the atmosphere is turbulent in nature. The air flow is made up of a series of eddies, which are carried past a fixed point by the horizontal wind. The vertical component of the wind speed, w′, at a point will vary continuously as the eddies pass, alternately being directed upward and downward. When evaporation is occurring, the air moving upward in the eddies will be wetter than the air moving downward. If we define q′ as the instantaneous departure of q from its mean value at the point, then the product w′q′ is the deviation of the instantaneous water-vapor flow from its mean value. The evaporation is found by averaging over time as shown by the overbar

$$E = \rho \overline{w' q'}$$

An instrument called the Evapotron has been developed to find E by this method *(Dyer and Maher 1965)*. It shows great promise as a research tool but has not yet been tried over forests.

The sensible heat flux is similarly dependent on turbulent flow, but here temperature takes the place of humidity.

$$H = C_p \rho \overline{w' T'}$$

The Fluxatron *(Dyer et al. 1957)* measures H in this way but also has not yet been applied to forests.

Difference Method

The energy balance equation (2) alone can be used to determine E only if the sensible heat flux is found independently; then H is subtracted from measured Rn to give E. I have called this the difference method, as it apparently has no other commonly used name.

The required sensible heat flux can be found by the eddy correlation method, or it can be found by using equations analogous to (10) and (11) for E. Substituting (9) into (7) and then into (4), and integrating, gives the profile equation for H as

$$H = -C_p \rho k^2 \frac{(u_2 - u_1)(T_2 - T_1)}{\left[\ln\left(\frac{z_2 - D}{z_1 - D}\right) - \psi\right]^2} \qquad (12)$$

The difficult measurement of $(q_2 - q_1)$ required for (10) is substituted for by the easier measurements of $(T_2 - T_1)$ and Rn. Accuracy is high over surfaces where evaporation is large and H is small.

The bulk aerodynamic equation for sensible heat flux is similar to (11):

$$H = - C_p \rho k^2 \frac{u_2}{\left[\ln \left(\frac{z_2 - D}{z_o} \right) - \psi \right]^2} (T_2 - T_o) \qquad (13)$$

Combining (13) with (2) is the bulk-difference method for evapotranspiration. A modification of this method has been used over a hardwood forest in Russia *(Rauner 1960; Dzerdzeevskii 1963)*. However, no independent checks of the results were made. The surface temperature, T_o, may be measured directly by infrared radiation measurement *(Fuchs and Tanner 1966)*. Comments applied to equation (11) also apply here.

Tanner *(1960b)* has proposed a modification of (12) similar to Deacon and Swinbank's *(1958)* modification of (10).

Bowen Ratio Method

The Bowen ratio is defined as H / L_vE. This ratio can be obtained from (10) and (12) and substituted into (2) to give, after rearrangement,

$$L_vE = \frac{Rn - S - M}{1 + \left[\frac{C_p (T_2 - T_1)}{L_v (q_2 - q_1)} \right]}$$

Use of the Bowen ratio (the term in brackets) eliminates any need for wind measurements, known heights, stability corrections, roughness length, or zero-plane displacement; but the difficult vapor concentration difference is required *(Suomi and Tanner 1958; Fritschen 1966)*. The ratio K_h / K_w should also appear in the bracketed term if it is not assumed equal to unity. The Bowen ratio method has also been called the energy balance method, but this name is misleading. Baumgartner, *(1956)* in his classic work on a fir forest in Austria, used this method, but no independent check on the evaporation data was obtained.

Combination Methods

Potential evapotranspiration is defined as the evaporation from a surface for which q_o is the saturation specific humidity at T_o. With this assumption, suitable combination of equations (2), (11), and (13) leads to

$$E_p = \frac{(\triangle / C_p)(Rn - S - M) + \rho h (q_{T2} - q_2)}{1 + (\triangle L_v / C_p)} \qquad (14)$$

$$h = \frac{k^2 u_2}{\left[\ln \left(\frac{z_2 - D}{z_o} \right) - \psi \right]^2}$$

where q_{T_2} is the saturation specific humidity at T_2 and $\triangle$ is the slope of the saturation specific humidity-temperature curve *(van Bavel 1966; Tanner and Fuchs 1968)*. With an empirical wind function for h, this is the well-known Penman *(1948)* method.

The "generalized combination method" for actual evaporation developed by Tanner and Fuchs *(1968)* is simply the bulk difference method described above as the combination of (13) and (2).

A commonly used method of estimating E is to determine E_p by (14) and then to use an empirical relationship of E / E_p to available soil water *(Denmead and Shaw 1962; Crawford and Linsley 1963)*. As soon as this relationship is put on a theoretical basis *(Visser 1963; Cowan 1965; Woo et al. 1966)*, the combination method for potential evapotranspiration and soil-water measurement may give an accurate measurement of evapotranspiration.

The combination method and soil-water approach are also the avenues to predicting effects of forest treatments on evapotranspiration, since they include all relevant variables. Micrometeorological studies of forests have already led to analysis of differences in evapotranspiration from different cover types *(Baumgartner 1967; Rauner 1965)*. All the relevant surface variables — albedo, surface temperature, roughness, stomatal resistance, root and soil water properties — as well as all necessary meteorological variables — will some day be included in a complete quantitative description of the whole soil-plant-atmosphere system.

PRACTICAL DIFFICULTIES

Instrumentation

The measurements needed for any of the micrometeorological methods unfortunately require sensitive instruments that are not as yet standardized. Net radiation can be measured with a variety of different instruments, some of which are commercially available *(Gates 1965; Federer 1967)*. Differences in wind speed, temperature, and vapor concentration between two heights require extremely accurate sensors because the differences are small. The required order of accuracy needed for the differences are 1 cm. per sec. for wind, and 0.02° C. for wet-bulb and dry-bulb temperature. Greater height differences allow lower absolute accuracy in the measurements. Anemometers meeting these requirements can be purchased. Temperature and water vapor sensors of sufficient accuracy are usually built by the investigator, but no commonly used design is available. An outstanding review of such instrumentation is given by Tanner *(1963)*.

If methods utilizing surface values of temperature and vapor concentration are used, the required accuracies are of a magnitude less than those given above. However, these methods require either an empirical wind function or determination of roughness length and zero-plane displacement from accurate wind profiles, and the assumption that these remain constant.

All the methods discussed here require time integration of the meteorological variables. Integration can be done either electronically at the site before recording, or by digital computer on a series of recorded, instantaneous values. Integration times may vary for different studies from 15 minutes up to half a day. Development of satisfactory recording systems is a significant electronics problem, especially for forest measurements where remote operating stations that may be unattended for periods of a week or more may be required. Calibration drift in either the sensors or the electronics is a serious problem for the systems that must be employed. Frequent interchange of sensors between heights is one way to reduce this problem *(Tanner 1960a)*. Compromises between the drift problem and unattended operation may be needed.

In short, a great deal of work is needed on instrumentation problems before micrometeorological methods can be easily applied to forests.

Advection

The current theory of the micrometeorological evaporation methods assumes a horizontally uniform, two-dimensional surface. If this assumption is not met, there will be a net horizontal transfer of energy into or out of the volume being measured. This horizontal transfer is called advection, and it is not accounted for by the theory. The three-dimensional form of forests and their horizontal variation imply that advection may be a serious problem in applying micrometeorological methods.

Absorption of the horizontal component of solar radiation is exemplified by isolated trees or stands that have a sunny side and a shadow. Hilly topography also produces inhomogeneities in horizontal solar and infrared transfers. Geiger *(1965, pp. 369-381)* and Lee *(1964)* have analyzed these situations. Lateral interception of water droplets as fog drip is an extreme example of horizontal advection of water vapor, but it can also occur in invisible forms.

Advection of sensible heat and water vapor occurs in three forms (fig. 1). Net movement into or out of a stand, or of individual trees below the tree tops, is called the clothesline effect *(Tanner 1957)*. There is no theory for this effect, and its magnitude has never been measured. Local clothesline advection produced by individual tree crowns and canopy openings causes local variation in energy balance and in mass transfer. Spatial integration then becomes necessary and can be achieved either by using several sensors at different locations or by raising the sensors higher above the canopy.

When sensors are elevated to obtain better spatial sampling and to obtain maximum possible vertical differences, a second

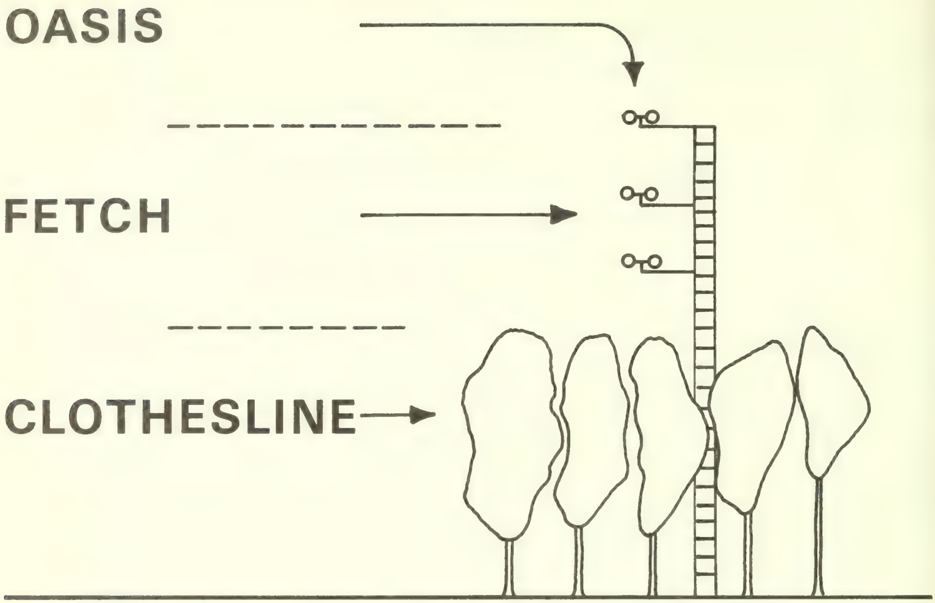

Figure 1.—The three kinds of advection, or net lateral energy transfer.

form of advection becomes important. Energy can be transferred laterally in the space between the top of the canopy and the top of the highest sensing instrument. With increasing height, the wind, temperature, and vapor concentration are affected more and more by surfaces farther upwind and less by the surface immediately below the sensor. The measured vertical gradients are then not representative of the underlying surface. The fetch requirement of a site is the minimum upwind distance at which a significantly different surface may exist without affecting conditions at the sensor height. This type of lateral transfer may thus be called fetch advection.

Several studies have been made of fetch requirements in the case of a dry surface upwind of a wet surface *(de Vries 1959; Philip 1959; Dyer 1963; Rider et al. 1963)*. Fetch advection can also be produced by a change in surface roughness that affects the downwind turbulent transfer coefficients *(Elliott 1958; Brooks 1961; Panofsky and Townsend 1964)*. A rough rule of thumb requires a fetch 50 to 100 times the highest sensor height above the zero plane. However, no measurements are available to test this rule over forests. The forest meteorologist is seriously squeezed between the minimum height allowed by clothesline advection and the maximum height allowed by fetch advection.

Energy can also be transferred to an area by horizontal transfer above the sensor height, then by vertical transfer to the surface. This third type of advection is called the oasis effect because the condition is most pronounced over desert oases. Oasis advection is satisfactorily measured by micrometeorological methods since the transfer is vertical at sensor height.

Clothesline advection is net horizontal transfer below the tops of the trees. Fetch advection is net horizontal transfer between the tree tops and the sensing instrument height. Oasis advection is net horizontal transfer above sensor height, or above treetop height if there are no sensors. The theoretical equations discussed in this paper are correct only for regions of height in which none of these three advection forms is appreciable; that is, only for regions in which all net transfer is vertical.

A form of vertical heat transfer within the volume being considered must also be mentioned. Studies by Denmead *(1964)* and Knoerr and Gay *(1965)* indicate that radiant energy absorbed at the upper surface of the forest canopy is in part converted to sensible heat, which is transferred downward into the canopy and used in increasing evaporation. The effective source level, and thus the zero-plane displacements for sensible heat, latent heat, and momentum, may be different. The effect of this phenomenon on the various micrometeorological evaporation methods has not yet been studied.

CONCLUSIONS

Forest hydrology research and forest watershed management have been hindered by lack of a satisfactory method for measuring forest evapotranspiration. Soil-water sampling used in the water balance is limited to periods greater than 3 days and is plagued by the problem of unmeasured deep seepage. Micrometerological methods, based on the energy balance and vapor transport, offer an approach to measuring evapotranspiration for periods as short as 15 minutes. However, only two successful studies applying these methods to forests have been reported *(Baumgartner 1956; Rauner 1960).*

Several different micrometeorological methods can be used to obtain nearly independent results. Future experiments should evaluate the usefulness and accuracy of these methods. The magnitude of advection error due to surface inhomogeneities, and consequent spatial sampling requirements, need study. Theoretical problems involving equality of the eddy diffusivities and the diabatic correction may not be serious for the accuracy required here. But problems with instrumentation require further research.

Combining micrometeorological theory with results from soil physics and plant physiology should lead to methods of predicting the effects of changes in the soil-plant-atmosphere system on evaporation.

■

APPENDIX

Notation

The units given below represent a consistent set, but they are by no means the only units that are commonly used in the soil-water budget method and the micrometeorological methods. Energy-flux values are more commonly given with time units in minutes rather than seconds, as shown here.

a	albedo	dimensionless
C_p	specific heat of air	(≈ 0.24) cal g^{-1} ^{0}K^{-1}
D	zero plane displacement	cm
E	evapotranspiration (rate)	g cm^{-2} sec^{-1}
$\hat{E}$	evapotranspiration (quantity)	cm
	[note $\hat{E} = \frac{1}{\rho_w}\int E\,dt$]	
E_p	potential evapotranspiration	g cm^{-2} sec^{-1}
e	vapor pressure	mb
F	streamflow	cm
G	deep seepage	cm
g	acceleration of gravity	(≈ 980) cm sec^{-2}
H	sensible heat flux	cal cm^{-2} sec^{-1}
h	wind function	cm sec^{-1}
K	diffusivity	cm^{2} sec^{-1}
k	von Karman constant	(≈ 0.42) dimensionless
L	Monin-Obukhov flux length	cm
L′	Monin-Obukhov gradient length	cm
L_v	heat of vaporization	(≈ 580) cal g^{-1}
M	heat for metabolism	cal cm^{-2} sec^{-1}
P	precipitation	cm
p	atmospheric pressure	mb
q	specific humidity (g water / g air)	dimensionless
q′	instantaneous deviation from mean specific humidity	dimensionless
q_{T2}	saturation specific humidity at temperature T_2	dimensionless
R_f	flux Richardson number	dimensionless
Ri	Richardson number	dimensionless
R_{td}	downward thermal radiation	cal cm^{-2} sec^{-1}
R_{tu}	upward thermal radiation	cal cm^{-2} sec^{-1}
Rn	net radiation	cal cm^{-2} sec^{-1}
R_s	downward solar radiation	cal cm^{-2} sec^{-1}
S	change in soil or vegetation heat storage	cal cm^{-2} sec^{-1}
T	temperature	^{o}K
T′	instantaneous deviation from mean air temperature	^{o}K
u	mean wind speed	cm sec^{-1}
u_*	friction velocity	cm sec^{-1}

w'	instantaneous vertical component of wind	cm sec^{-1}
z	height	cm
z_0	roughness length	cm
$\triangle$	slope of saturation specific humidity-temperature curve	$^{o}K^{-1}$
$\triangle W$	change in soil water content	cm
ε	thermal emissivity	dimensionless
ρ	air density	(≈ 0.0012) g cm^{-3}
ρ_w	water density	(≈ 1.00) g cm^{-3}
σ	Stefan Boltzmann constant	$(\approx 5.7 \times 10^{-5})$ g sec^{-3} $^{o}K^{-1}$
τ	momentum flux	g cm^{-1} sec^{-2}
ϕ	diabatic correction	dimensionless
ψ	integrated diabatic correction	dimensionless

Subscript $_o$ refers to the surface; $_1$ and $_2$ refer to heights above the surface.

Subscripts $_m$, $_h$, and $_w$ on ϕ and K refer to momentum, heat, and water vapor, respectively.

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